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Image Inpainting Using Image Interpolation - An Analysis

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Abstract

Image inpainting is a computer technique of filling lost regions of an image by using available information from the surrounding area. This digital image inpainting technique has wider applications like image restoration, dis-occlusion and image/video compression. The traditional image inpainting approaches Partial Differential Equation (PDE) based method and Exemplar based method mainly focus on the size of the target region to be filled. PDE is a pixel oriented method and works well if the region to be filled is small. On the other hand exemplar based method is a patch based method and works well if the region to be filled is large. This paper proposes another new technique called image interpolation technique and describes how this technique can be used effectively for image inpainting without giving much focus on the size of the target region.

Key-words: Image Inpainting, Partial Differential Equation based, Exemplar based, Image Interpolation.

1. Introduction

Image inpainting carries a prominent place in Digital Image Processing (DIP). Image Inpainting is the process of changing the deterioration (damaged part) such as cracks or scratches in the image, dust spots in paintings, adding or removing elements from images. After image inpainting an observer or an ordinary person cannot identify that some alternations has taken place in that image. Advances in technology enabled transition from traditional time consuming retouching methods to fast digital inpainting technology. Image inpainting was done earlier by using different hand

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retouching techniques manually that leads to time consuming process in image inpainting. This led to the development of sophisticated algorithms for making image inpainting process as an automatic process and it will be very fast and more flexible for implementing. Image inpainting concentrate on re-building lost or damaged portion of an image for making it more accurate and restore it in a desired form. Image Inpainting helps for restoring images, but demerit is that, it cannot create the original image back. Instead it tries to develop an image having a close resemblance to the old image. Applications includes removing unwanted parts such as scratches, cracks, blemishes in face, spots in old photos, text, logos or watermark in images [1].

Image inpainting have three different types of approaches namely structural image inpainting, textural image inpainting and hybrid image inpainting. Structural inpainting uses knowledge of geometric structure of the area where damage has occurred for filling damaged portions of the image. The structural based method is an iterative procedure which propagates the information regarding the boundary of the damaged portion of the image to the centre of the same region. Textural method on the other hand uses a pattern of similarities, which is repetitive that can be used for filling the portion. While hybrid image inpainting approach combine both structure and texture based methods. The main concept of using this technique is by dividing the original image two parts. One part contains the structure part of the image and other contains the texture part of the image. The structure part and texture part are inpainted with their respective algorithms. After this process two parts are combined to get the desired result [2].

Presently there exist two popular image inpainting approaches named as Partial Differential Equation (PDE) Based method and Exemplar Based method [1]. PDE is a structure based method. PDE has a differential equation that contains one or more variables and its derivatives. This method propagates geometric details from border of the damaged area to the inner part of the area itself. These lines of information are called isophotes or level lines. The geometry of target area is to be completed in the manner that angle between edge of the border pixel and gradient of the image has to be perpendicular. It is a type of iterative algorithm. Gradient of image denotes direction of the area to be filled. This algorithm works well for filling small region whose information is lost while acquiring the image. But it will take too much time for filling large region and partially filled regions. Further the result produced by this method is not good in the case of large missed texture regions [2][3]. Exemplar-based method uses patches to fill damaged region of an image. A patch is a small portion of an image having a group of pixels and its size is less than the size of available region and damaged region. Initially, boundary pixels of the target area are identified and priorities are given to these pixels. Then patches are formed with boundary pixels as centre and patches are formed by including certain pixels from the available area. The available pixels in the patch from the target area form a basis for searching similar pixels in the source area. The best match is identified with the minimum of sum of squared difference (SSD) between patch having the highest priority (best exemplar) and the patches in the source region. SSD method is employed to measure the similarities between patches having fixed size. Then the most similar patch is selected and pasted in the damaged area [4]. After the filling process the boundary gets altered. This process continues until the damaged region fills completely [5]. PDE works well for retrieving small missed or damaged regions whereas exemplar based method works worth for large regions. The two methods have some limitations. PDE impose some blur while try to inpaint large regions. Exemplar Based method does not work for an image that do not have any structural or textured information. Searching best exemplar is a time taking process. In order to overcome these drawbacks of the above two methods image interpolation technique has been recommended in the literature. Process of obtaining new coordinate points within the range of a discrete set of available data points is known as image interpolation. Interpolation fixes problems in PDE and Exemplar Based Image Inpainting by filling small and large areas. It fills the area without giving much focus to the size of the region.

2. Method

A. Partial Differential Equation Based Method (PDE)

PDE based on diffusion. PDE based image inpainting algorithm continues with geometric and photometric information that appears on the border of the damaged target area and propagate the border information in direction of minimum changes using isophotes lines [1].

Review on Bertalamio's Image Inpainting Algorithm Using PDE

The three main steps included in the algorithm are selecting the damaged region to be inpainted, complete the geometry of the damaged target region, fill the geometry of the damaged or target region.

Let I represent an input image, target region Ω and its boundary $\delta\Omega$.

Step1: Select the area to be inpainted or object to be removed by the user.

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Step 2: The information to be propagated is denoted as L. For completing the geometry change of L (gradient of L denoted ∇L) has to be propagated perpendicular to the direction of $\vec{N}$ which means,

The equation (1) says that the gradient of information (∇L) does not change along the direction of $\vec{N}$ that is it is constant along the direction $\vec{N}$ Can be written in another form as,

$$\vec{N} = \nabla L^{\perp} \qquad (2)$$

$$\text{Where } L = \Delta I \qquad (3)$$

(The symbol Δ denotes change in the information)

The image has to be changed in time according to the requirement.

$$\frac{\partial I}{\partial t} = \nabla L . \vec{N} \qquad (4)$$

The symbol ∂ is used to indicate partial derivative (change in image with respect to time)

It reaches in steady state means,

$$\frac{\partial I}{\partial t} = 0$$

Step 3: Fill the geometry using Laplacian operator.

Laplacian is the simplest measure of smoothness; it is the second derivative of the image.

$$\textbf{i.e } \nabla I = I_{xx} + I_{yy}$$

The symbol ∇ indicates change in image. Combining equations (1), (2), (3) and (4),

$$\frac{\partial I}{\partial t} = \nabla(\Delta I).\ \nabla^{\perp} I$$

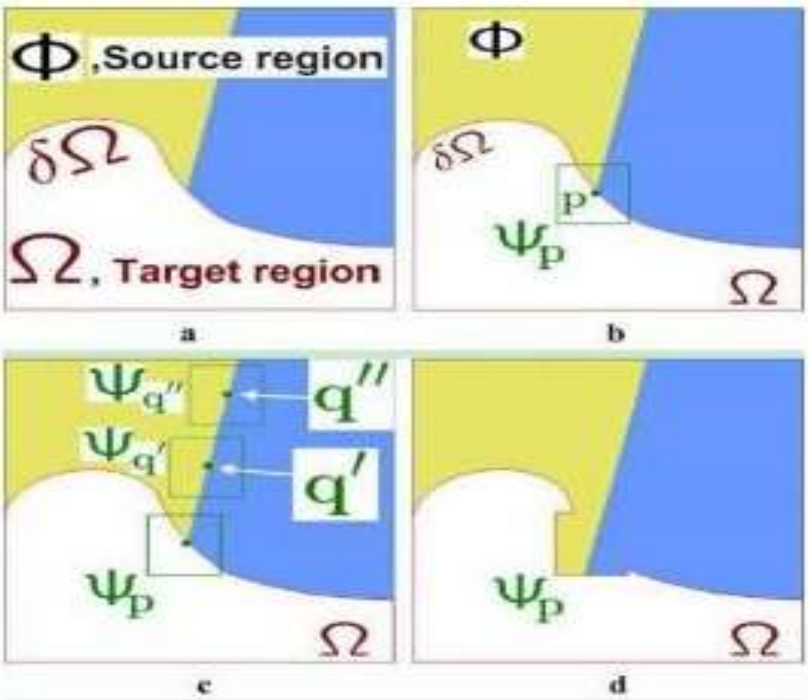
Since it is an iterative process continue the process until it reaches steady state. It reaches in steady state means,

$$\frac{\partial I}{\partial t} = \nabla(\Delta I).\ \nabla^{\perp} I = 0$$

B. Exemplar Based Method

Exemplar based method easily fills larger areas and it does not result in so much blur as partial differential equation does. It works better for an image that contains structural and textural information. The area to be inpainted is specified by the user through colour selection or region selection in the base image [4].

Fig. 1- Procedure for Exemplar based Image Inpainitng(a) image I with Φ as Source Region and Ω as Damaged Area and $\delta\Omega$ as Contour of the Damaged Area. (b) Ψp Patch Centred at 'p'on the Border of Damaged Area. (c)The Most Matching Patches for Ψp Lie on the Boundary between two Patches in the source Region Denoted Ψq' and Ψq''(d) Best Matching Patch has been Copied into the Position Occupied Ψp.



Review of Criminisi Region Filling Algorithm

Step 1: The user selects the damaged region and remaining part of the image considered as source region Φ. Step 2: Find border δΩ of the damaged area Ω, if δΩ = Φ exit, otherwise continue the next step.

Step 3: Priority of bordel pixel p calculated as product of two terms,

Priority(p) = C(p)× D(p)

Confidence term C(p) measures reliable information amount in patch ψ_p and calculated as,

$$C(p) = \frac{\sum_{q \in \psi_{p \cap \phi}} C(q)}{|\psi_p|}$$

where 'q' pixel in the source region Φ.

Where $|\psi_p|$ shows number of pixels in patch ψ_p. During initialization C(p) = 1 if p ∈ Φ and C(p) = 0, p ∈ Φ. The data term D(p) is calculated as strength function of isophotes hitting contour δΩ at each iteration and is defined $D(p) = \frac{|\nabla I_p^{\perp} . n_p|}{\alpha}$ where $\nabla I_p^{\perp}$ is the pixel gradient and n_p is a unit vector orthogonal to boundary δΩ and α is a normalization factor (α = 255 if the image is a gray level image).

Step 4: Match this highest priority patch with entire image patches of the source region from centre pixel co-ordinate (0, 0) to (x, y) co-ordinate and identify the matched window.

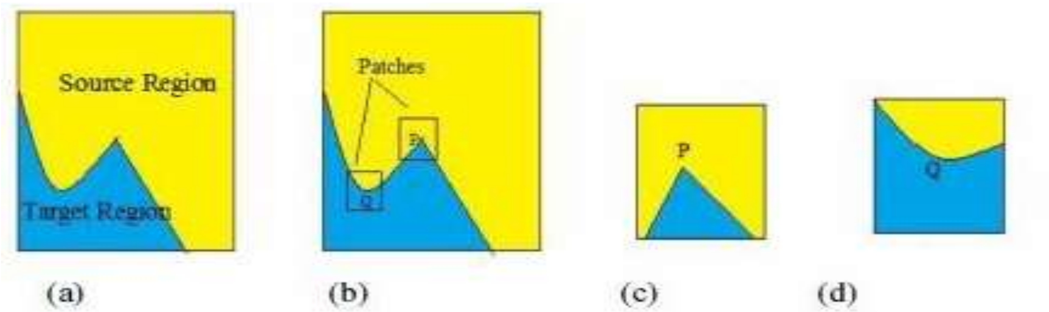
Here best matching patch ψ_p found out from source region. Patches are compared using Sum of Squared Distance (SSD) and patch having minimum SSD is the best matching patch.

$$\psi_q' = \arg\min SSD(\psi_p, \psi_q)$$

Where $\psi_q \in \Phi$, q as the centre of patch

The best matching patch is copied to target patch. Thus target region gets reduced.

Fig. 2- Exemplar based Method Illustration



Confidence Term (a) Image to be inpainted; (b) Patches centred around P and Q; (c) Patch with maximum confidence value; (d) Patch with low confidence value.

Step 5: The above steps are continued until damaged area fills completely.

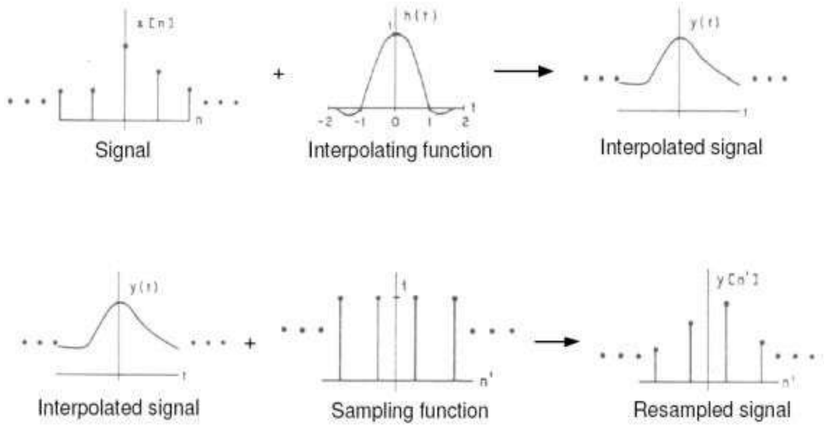
The two popular methods above described have some drawbacks. PDE fails for filling large and partially filled missing regions whereas exemplar based method fails in filling smaller regions and it works better for images having structure or texture areas. Image interpolation technique is proposed in this paper to overcome these drawbacks of PDE and exemplar based method. This technique does not focus on size of the damaged region whereas other two methods focus on size of the damaged region.

C. Image Interpolation Method

Image interpolation Method is needed when an image is re-sized or distorted from one pixel coordinates to another. When re-sizing, number of pixels in the image either decreases or increases. These two conditions can be fixed by using image interpolation. Image interpolation is a process to estimate values at unknown points according to the values at surrounding points [6].

Transforming a discrete image defined at one set of coordinate locations to a new set of coordinate locations [7] two processes are involved, Image interpolation and re-sampling. It is called re-sampling because, in the first step image is converted into samples. Then the sampled image is interpolated using interpolation functions into a continuous image. Then the interpolated continuous image is again sampled to convert it into a digital image. This is illustrated in the following figure 3. Continous function y(t) is produced by convolution between discrete function and interpolating function denoted as x(n) and h(t) respectively. Again continuous function multiplied by a sampling function to produce a discrete function. This sampled image is at new coordinate points. So this is a re-sampling process. Re-sampling process is used in many image processing operations such as rotation and resizing of images [8].

Fig. 3- The Process of Re-sampling Uses Interpolation Functions



This is the concept used in image inpainting also. The missed or lost part of the present image has to be filled with pixels from the neighbouring area. So image interpolation can effectively used for finding pixels for doing image inpainting. There are so many image interpolation methods available such as nearest neighbour, Bi-linear interpolation, Bi-cubic interpolation, B-spline interpolation and Kriging interpolation. Each of these interpolation methods has its own advantages and disadvantages. A particular interpolation method alone cannot be used in all type of situations.

Sample data taken for specific purpose and the tolerance of estimation error determine the type of interpolation method to use in a particular occasion [9].

3. Literature Review

A. Partial Differential Equation Based Method

PDE is a diffusion oriented method. The process involved includes propagating higher order derivatives of pixels that lie on the border of the damaged area. These intensity values are forwarded continuously from border side to the inner side of the missing portion of the image. These equal intensity values are called isophotes or gray levels [1].

In this Paper [1] the author Bertalamio proposed an algorithm for digital image inpainting for still images. The user has to choose the region to be filled. Initially this method completes geometry of the damaged region by finding the gradient of the pixel available in the border information. This information is propagated to inner portion of the damaged area by taking Laplacian filter of the original image. This algorithm does not work well in the case of images containing structures or textures and results in blurred image.

In this paper [3] the author Rajkumar Biradar proposes an image inpainting method. This method use median filter instead of Laplacian filter as proposed in paper [1]. The median filter preserves the edge of the damaged area. Images having texture background leave distinguishable edges around damaged region. It is the drawback of this method. It fails for filling textured region.

The author in paper [10] proposed a reconstruction method in latent print. Latent print is useful for restoring missing ridges in thump impression. Finger print divided into three types as rolled, flat and latent impression. In rolled impression finger rolled from one side to the other for obtaining impression of a larger area. In flat impression finger pressed down with moderate pressure. These two methods are subject to retake until the desired quality is attained. Latent finger prints are generally discovered in crime scene which does not provide any retake. So the missing ridge structures cannot be extracted manually. Identifying and filling missing structure of such fingerprint is a challenging task in image inpainting. So the missing latent print can be restored by combining rolled and flat technologies. In this method Partial Differential Equation inpainting fills small fissures (cracks) in ridge structures. It also uses exemplar based image inpainting technique to fill in large to medium sized voids regions.

All PDE based method for image inpainting find difficulty in implementing since it contains complex iterative methods. Some steps are numerically does not come to a finishing point and inpainting process become too slowly.

B. Exemplar based Method

Exemplar based method is a patch oriented method. It is faster than PDE and works better for completing larger areas. Best patch selected pasted in damaged area. In this way completes the missed area.

In paper [4] Bertalamio proposed an algorithm for simultaneous filling of structured and textured details in the missing part of damaged area of an image. The basic concept is that to decompose the original image into two parts of different characteristics. The first decomposed part of the image is inpainted using PDE proposed in paper [1]. The second decomposed part of the image inpainted with texture synthesis algorithm. Texture synthesis algorithm fills missed parts of an image using textures from available information from original image. Then the two reconstructed images are combined together for getting the desired result. This method is complicated and time consuming and is applicable for an image having texture patterns.

The author proposed an algorithm named sketch guided texture based image inpainting [12] in this paper. Initially missed area identified. Then sketch of missing portion is constructed. Then completed lines of any orientation are completed along the sketch of the image based similar texture area pattern with no intersection are constructed, then nearby lines are paired. Area in between these lines is filled with similar texture pattern and this process continued until all the pairing lines of damaged portion filled. Thus area between lines is filled. This image is applicable only image containing texture patterns.

In this paper [13] proposed exemplar based image inpainting. The filling priority equation consists of confidence term denoted by C(p). As filling process proceeds, the value of C(p) descends and the priority value containing C(p) also descends. This situation is called ‘dropping effect’. It largely damages the central inpainting region and in some case do not get desirable result. The value of confidence term is essential for controlling the process. Vagueness and ambiguity can be managed efficiently by Fuzzy techniques. All part of fuzzy method is done on second step of exemplar based image inpainting.

Bertalmio M et.al in their paper [14] proposed a modified exemplar based inpainting algorithm. This algorithm investigates natural image patches sparsity. The first operation of patch propagation includes patch selection and then come patch inpainting. In patch selection method a patch having higher priority selected for pasting in the damaged area. Patch priority is defined using structure parsity. Structure parsity is a measure of distribution of likeness of a patch with its neighbouring patches. A patch on border which has sparser non-zero similarities has larger priority. The selected patch on border area is inpainted by linear combination of patches in the source region regularized by l^0 sparseness prior.

The author in paper [15] presented two main sequential operations. As a first step original image having high resolution converted into low resolution image. An image inpainting algorithm presented in paper [4] is applied to fill holes of resolution image. This image having lesser number of pixels than the original image is inpainted several times by changing different settings such as size, filling order, rotating angle etc. Exemplar based method is used for inpainting different versions of input image. Second operation is converting this low resolution images into original high resolution images after the image inpainting operation.

In this paper [16] developed an algorithm named Successive Elimination Algorithms (SEA) in which the priority of patches on boundary of damaged region is calculated as proposed in paper [4] .Then the patch with highest priority is taken and sum of absolute difference (SAD) of the current patch and patches on the source region is compared. Then the patch having minimum SAD value is taken and replace with the current patch. Then take the patch having next higher priority. This process is continued until damaged area is filled.

In this paper [17] showed a small modification in the [4] algorithm. Paper [4] considers texture and structure details of image to calculate the priority of border patches. But this algorithm failed to combine texture and structure information when finding optimum matching block. Since an image is considered as a mixture of colour and structure information, in this paper structure information of image is taken by finding first or second derivative. This factor is also added for finding the priority of patches. Then filling of the damaged area follows as in the case of traditional exemplar based method.

C. Image Interpolation

In this paper [18] Proposed an image inpainting algorithm in which more than one algorithms are used for edge and area restoration. Initially, pixels around the damaged area are identified using canny edge detector. Structure tensor used to represent gradient or information about edges and changes in brightness level. Using structure tensor the original image (including the damaged region) is divided into textured and non-textured regions. The textured regions are restored using exemplar based method and non textured region are restored using Telea method. The curve regions are filled by using Cubic Spline interpolation method. The drawback of this method is usage of so many algorithms yield to more computational time.

In this paper [19] made a study on different existing methods of image interpolation techniques. Image Interpolation algorithms like nearest neighbour and bilinear interpolation [20] exhibit widest usage and they show computational simplicity. 'Mitchell and Lanczos' interpolation method work based on a window function of limited spatial support for the purpose of reducing spectral leakage and loss of spatial resolution. This method requires a number of hardware resources. Quadratic image interpolation [21] nowadays emerged with a very good visual results but its main disadvantage is computational cost for its coding.

In this paper [22] proposed an image inpainting approach based on image interpolation .This method is a combination of High Dimensional Model Representation (HDML) and Lagrange Interpolation. Langrage interpolation is a type of interpolation method which uses polynomials as interpolation functions by taking certain values at arbitrary points. The author considers image inpainting using interpolation problem. They use HDML method and use high dimensional data with lower dimensional data. The author considers this as a hierarchical approach and segment missing areas into smaller areas. Then start inpainting from the smallest area. Author compares new designed approach to the existing approaches. By comparing with Criminisi's exemplar based algorithm the proposed technique has high PSNR value. This method is easy to implement. This method uses polynomials of higher power and more computational time is needed.

In this paper [23] Proposed image restoration method using interpolation. Image restoration aims for capturing noisy image and estimate original image. Some type of noise added to input image and noise reduced implementing iterative method. After doing image inpainting image interpolation process is applied. For this, digital image converted to continuous signal by taking sampling of input image. Resolution enhancement, error concealment etc are the common uses of image interpolation. This algorithm contains more complicated steps and consumes more time to implement.

Proposed technique in paper [24] is object removal from an image by using Kriging Interpolation technique. This technique uses available near pixel values and distance (weight) for calculating unknown values. The sum of these weights should be equal to one. Initially user has to select part of image to be removed. This helps to determine the mask to be applied on the image. Then input image and mask divided into K×K block. After that Kriging interpolation technique is applied to each block. Kriging algorithm compares input image and mask block by block and applies the algorithm. Initially similar pixels from both blocks identified. These identified pixels are calculated for their values. After that entire cells are merged into one image to get desired output image. Block size holds a prominent part for getting final output. Size of block and PSNR value are inversely proportional, but block size and MSE value are directly proportional. Using small block size results in desired output.

In this paper [25] the author uses Bicubic interpolation (BI) image technique. This technique is used for frame enhancement of camera based traffic monitoring. Cubic interpolation is key algorithm utilized in BI. Interpolated pixel value determined by investigation of neighbouring pixels.

In this paper [26] the author proposed a method of removing white degradations occurred in images. The algorithm used bi-cubic interpolation method for image inpainting. The input data to the algorithm contains an image with damaged part and mask of degradation. The mask contains coordinates of damaged region. Considering the steps included in this procedure as four stages, in the first stage a patch is created around the missing target by using sixteen pixels. First stage sends mentioned sixteen pixels to following two stages. Second stage produces four lines each with four pixels using with the above mentioned sixteen pixels. Four lines include one horizontal, one vertical and two diagonal lines. Result of second stage becomes input to third stage. This stage assumes each line of five pixel line with a missing line. It predicts an intensity value for centre pixel using 1-D bi-cubic interpolation. Centre pixel carries four predictions. Missing pixel is the intersection point of all four lines.

4. Gaps in Literature Review

Image inpainting methods classified into two as Partial Differential Equation (PDE) based and Exemplar based. PDE based algorithm works well and produce good results for lesser area. This PDE based method results in blurred image when it is used for inpainting larger areas. Exemplar-based image inpainting uses image exemplars or blocks or patches or samples that are derived either from the same image or other images. The main drawbacks of exemplar-based method are input images should contain structure or texture patterns, identifying the value for parameter settings and estimating the filling order of patches. The literature reviewed above contains so many image inpainting methods in which some of them uses PDE, some others uses Exemplar based and certain inpainting methods uses the combinations of these two methods. But in all these cases, the resultant output image exhibits the drawback of both of these methods. In order to overcome the drawbacks of above two methods, image interpolation technique has evolved for image inpainting. Image interpolation fills image gaps without considering whether the target areas are small or large. To resize or fill the gaps in an image, every pixel in the new location must be mapped back to a location in the old image in order to calculate the value of a new pixel. There are so many image interpolation techniques found in literature. Therefore, image interpolation technique can be used for overcoming the drawbacks of existing methods of image inpainting.

5. Conclusion

This technique overcomes the existing drawbacks of traditional methods. The two popular image inpainting concepts Partial differential equation based and Exemplar based methods are analyzed and reviewed in detail. These two techniques have advantages as well as disadvantages. PDE works well for small regions while exemplar based method works well for large regions and fails in filling curved portions. So by literature review it is found that pixel oriented method is better for filling damaged regions it does not give much focus on the size of the damaged region. Image interpolation is a pixel oriented technique which finds new pixel values from existing pixel values. Therefore image interpolation technique can efficiently be used for doing image inpainting.

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