Image Retrieval Using Digital Image Inpainting Techniques

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ABSTRACT

Image retrieval is an inverse problem in digital image processing. In this paper, the authors deal with restoration of image using digitally image inpainting methods. In this inpainting technique, one can extract a missing an important part or can fill unwanted parts of an image, so as to recover original information without loss. They are using semi-automatic and fast image inpainting methods and compared their result in terms of image quality assessment parameters such as PSNR, MSE, as well as required timing constraints. The observational as well as statistical results show that the fast image inpainting technique is superior in all respects for any kinds of multimedia image application.

KEYWORDS

Image Inpainting, Image Quality Assessment, Image Restoration

1. INTRODUCTION

Today, one deals with digital images on a daily basis. Digital images play an important role in daily life applications such as biomedical imaging, satellite imaging, multimedia imaging system and R&D imaging. Digital image processing enables one to extract the pictorial details and useful information from a given low quality image. The field of image processing has grown considerably during the last few decades, with the developments in digital computer technology in terms of improvement in size, speed and cost effectiveness. Today, the technology has reached such a level that one can purchase a compact image processing system off the shelf to capture and manipulate an image the way one wants.

To study the digital image processing the whole process may be divided into number of stages out of which image restoration concerns the removal or reduction of degradations which have occurred during the acquisition of the image. Advances of technology made possible the transition from traditional manual retouching methods to digital techniques. Digital image inpainting is an important issue in the domain of image restoration and an international interesting research topic in recent years, and it has different terminology names in different areas. For example, it is called error concealment in the signal transmission, and is called art inpainting etc. Digital inpainting is one of the techniques of filling in the missing regions of an image using information from surrounding area. The term digital in painting was introduced by Bertalmio (Bertalmio et al., 2000) in the year 2000.

In the parlance of digital inpainting, the missing region is often referred to as hole and is usually provided by the user in the form of mask or can be obtained by applying different techniques. Digital inpainting has found wide spread use in many applications such as retrieval of damaged old paintings and photographs, removal of undesired objects and writings on photographs, transmission error recovery in images, computer-assisted multimedia editing and replacing large regions in an image for privacy protection. The goal of the inpainting technique is to modify the damaged region in an image in such a way that the inpainted region is undetectable to a neutral observer. Alternately, the objective of inpainting is to reconstruct the missing or damaged portions of the work, in order to make it more legible and restore its unity.

Early artistic creation could not have survived over the years if it was not for the image and art restoration artists that brought old or damaged paintings back to the original or a close-to-the-original state. Artwork dating back to the Middle Ages was already in need of retrieval towards the end of this period of European history, as noted by Emile (2019). At the beginning of the Renaissance era, the main concern regarding medieval artwork was to bring it up to date, which many times required reconstructing missing or deteriorated parts of a canvas, by ðlling in existent gaps with visually pleasing content. Thus, it can be said that almost as old as art itself is the practice of making modiðcations to paintings, in such a way that if an observer would look at the modiðed work of art, without knowing the original, he wouldn't be able to perceive any alteration. This practice is traditionally carried out by retrieval experts, such as museum art restorers, and it is commonly known as retouching or inpainting. Its desired outcome is to make a damaged artwork more discernible, while restoring its unity. An example of a painting that has been the subject of a manually restoration process, that involved inpainting, is given in following Figure1and Figure2.

Here, we have discussed some practical examples of image inpainting concepts which may clear out the complete idea of our proposed work.

Figure 1. Self-portrait by Margareta Depner - before and after manual restoration

(a)   (b)

Figure 2. Left: Damaged Image. Right: Restored Image by Inpainting Technique

2. LITERATURE REVIEW

Various literatures on digital inpainting show the existing modality. Some of the literatures are presented here. Komal S. Mahajan, Prof. M. B. Vaidya Image inpainting Techniques: A survey (2012), paper describes that the main goal of the inpainting algorithm is to modify the damaged region in an image in such a way that the inpainted region is undetectable to the ordinary observers who are not familiar with the original image. This proposed work presents a brief survey of different image inpainting techniques and comparative study of these techniques. In this paper we provide a review of different techniques used for image Inpainting. Manuel M. Oliveira, Yu-Sung Chang Fast Digital Image Inpainting paper (2001), defines presented a simple and fast inpainting algorithm based on an isotropic diffusion model extended with the notion of user-provided diffusion barriers. The results produced by this simple model are, in many cases, comparable to previously known non-linear inpainting models, but two to three orders of magnitude faster, thus making inpainting practical for interactive applications. Mortaza Mokhtari Nazarlu and Javad Badali Image Inpainting System Model Based on Evaluation (2013), paper proposes image segmentation algorithm and inpainting algorithm are the key ingredients in the process of inpainting after studying many image-inpainting algorithms. Therefore, analyzing, comparing and verifying the segment algorithm and inpainting algorithms, the system model which owns segment and repair evaluation function is constructed, so it can optimize the segmentation algorithms and the inpainting algorithms. Yen-Lin-Chen Automatic Text Extraction, Removal &Inpainting of Complex Document Images (2012), proposes a system that extracts text lines and restores text-removed images from various types of complex document images of mixed and overlapping texts, graphics and pictures. The system first decomposes the document image into distinct object planes to separate homogeneous objects, including textual regions of interest, non text objects and background textures. Afterwards, a computationally efficient text removal and inpainting process, based on an effective adaptive inpainting neighborhood adjustment scheme, is applied to the obtained text-line regions to produce a clear non-text restored background image. Emma Naden, Thomas März& Colin B. Macdonald Anisotropic Diffusion Filtering of Images on Curved Surfaces (2014), demonstrate a method for filtering images defined on curved surfaces embedded in 3D. Applications are noise removal and the creation of artistic effects. This approach relies on in-surface diffusion: they formulate Weickert's edge/coherence enhancing diffusion models in a surface-intrinsic

way. These diffusion processes are anisotropic and the equations depend nonlinearly on the data. The surface-intrinsic equations are dealt with the closest point method, a technique for solving partial differential equations (PDEs) on general surfaces. Guillermo Sapiro Image Inpainting(n.d.), present algorithms for automatic digital inpainting using a partial differential equation that propagates information (the Laplacian of the image) in the direction of the isophotes (edges). The proposed algorithm shows that both the gradient direction (geometry) and the gray-scale values (photometry) of the image should be propagated inside the region to be filled in, making clear the need for high-order PDEs in image processing. T. Bret schneider, O. Kao Detection and Removal of Scratches in Digitized Film Sequences, describes a method for the detection and removal of scratches in digitized film sequences is discussed. The proposed technique highlights the physical structure of the scratch to distinguish between an actual scratch and an image feature. Anupam, Pulkit Goyal & Sapan Diwakar Fast and Enhanced Algorithm for Exemplar Based Image Inpainting (2010), present an algorithm that improves and extends a previously proposed algorithm and provides faster inpainting. Using our approach, one can inpaint large regions (e.g. remove an object etc.) as well as recover small portions (e.g. restore a photograph by removing cracks etc.). The inpainting is based on the exemplar based approach. The basic idea behind this approach is to find examples (i.e. patches) from the image and replace the lost data with it. This technique can be used in restoring old photographs or damaged film. It can also remove superimposed text like dates, subtitles etc.; or even entire objects from the image like microphones or wires to produce special effects. One of the earlier work in analyzing the error in image inpainting with the shape of the domain of inpainting was performed by Chan.et. Al (2006). In this important work, they showed that the quality of digital image inpainting depends more on the shape of the image inpainting domain than the size or total area of the inpainting domain. In effect, they discussed that inpainting techniques that use PDE based inpainting techniques are effective in inpainting small narrow smooth regions as they are based on smoothing.

Due to extensive research and rapid technology advancements, new digital image inpainting methods continuously emerge, trying to achieve better performance in terms of quality of the resultant images. Consequently, an accurate method for evaluating the inpainting quality is required, in order to establish if newly developed methods increase the quality of the inpainted images. Thus, from the above literature studies, some of the inpainting methods show very good result while some of them require re-modification in order to enhance the image quality which motivated us to develop semi-automatic and fast image inpainting technique to restore the degraded image.

2.1 Problem Definition

Most of the image retrieval problems are highly affected by external noisy factors such as scratch, cracks, torn films, old age photo quality and some by internal noisy factors such as blur atmospheric effect during capturing, etc. Internal noise can be easily recovered by designing some digital filters. But to remove the external noise is a prime challenge.

Historically, inpainting has been manually performed by artists to restore damaged paintings and photographs with small defects such as small cracks, scratches, red-eye and dust spots i.e. external noisy factors. Manual image inpainting process is costly and very tedious, less accurate as it is based on trial-and-error form and too much time consuming.

Most of the digital inpainting techniques require noise-free as well as blur-free image for processing of restoration otherwise those techniques produces images with less visual quality. Most of the existing work is limited to gray scale images only.

Hence, from the above problem analysis, it is now on great demand to develop such a system that will helpful to improve the overall performance of digital inpainting system.

3. IMAGE RETRIEVAL USING IMAGE INPAINTING TECHNIQUES

3.1 Image Retrieval

Image retrieval is one of the important aspects of digital image processing after image enhancement. Image restoration concerns the removal or reduction of degradations which have occurred during the acquisition of the image. Restoration of old photographs is of great importance to preserve the originality of the medium in terms of "a historical record" as well as the means to quality improvement for reproduction purposes. Old photographs often suffer damage and quality degradation through inappropriate storage and wear and tear, and sometimes, even during production. These defects were categorized as dirt, line scratches and brightness variation. Image retrieval technique is required to restore the degraded form of an image.

3.2 Image Degradation Factor

The acquired image usually represents the scene usually in an unsatisfactory manner. Since, real imaging systems as well as imaging conditions are imperfect: an observed image represents only a degraded version of the original scene. These degradations in the images are caused due to various factors such as blur, noise and aliasing. Factors like motion of the scene, wrong focus, atmospheric turbulence and optical point spread function can introduce degradations in an image known as blur, during the imaging process. Removing the effect of blurring in an image is known as deblurring which is a well-known image enhancement technique. If the conditions at the time of acquiring an image are known, it is much easier to de-blur the image accurately.

3.3 Image Restoration Model

Following Figure 3 shows an image restoration model.

From the above model, $g(x, y) = h(x, y) * f(x, y) + n(x, y)$ represents image degraded model. This degraded image $g(x, y)$ can be restored using restoration model to get restored (noise-free, de-blurred) image $f^\wedge(x, y)$.

Image restoration technique can be done by using several types of deblurring, denoising algorithms and modern digital inpainting techniques. At this juncture, it is pertinent to note that inpainting is fundamentally different from classical de-noising algorithms. In case of denoising algorithms, the underlying signal is corrupted by noise and de-noising algorithms try to recover the original signal by modeling the noise and statistical estimation. On the other hand, in inpainting, the regions of missing information in the original signal are large and inpainting algorithm attempts to re-create it using the surrounding information. Hence, denoising algorithms are not applicable in inpainting applications. The examples representing de-noising and inpainting are presented in Figure4 (a) and Figure4 (b) respectively.

Figure 3. Image Restoration Model
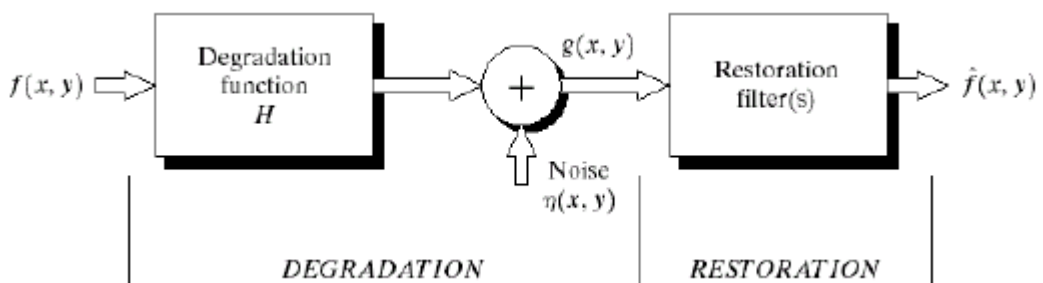
From Figure 4 (a) original image can be restored by using complex Denoising algorithm while from Figure4 (b) original image can be restored by using inpainting techniques.

3.4 Digital Image Inpainting

Digital image inpainting technique can be used to recover internal noise such as noise generated during image capturing process (Blur, Motion, Atmospheric Effect etc.) as well as external noise such as degraded quality of old aged image, scratch or torned image etc. Reconstruction of missing or damaged portions of images is an ancient practice used extensively in art work retrieval. Also known as inpainting or retouching, this activity consists of filling in the missing areas or modifying the damaged ones in a non-detectable way by an observer not familiar with the original images.

Most Inpainting methods work as follows: -

In the first step of Inpainting method the user manually selects the portions of the image that will be restored. The image retrieval is done automatically, by filling these regions in with new information coming from the surrounding pixels or from the whole image. The algorithms proposed for Inpainting use the information from surrounding portions of image to inpaint the selected region.

There are mainly three approaches for inpainting as follows: -

1. The first approach deals with the retrieval of films.
2. The second class of algorithm deals with disocclusions.
3. Third class of algorithm deals with retrieval of textures in the image.

Conventionally, inpainting is carried out by professional artist and usually is very time-consuming process because it was the manual process. The main goal of this process is to reconstruct damaged parts or missing parts of image as fast as possible. In this paper, we have implemented the semi-automatic and fast image inpainting technique for image retrieval application.

3.4.1 Semi-automatic Image Inpainting Technique

Semi-automatic image inpainting with user assistance, in the form of guide lines to help in structure completion has found favor with researchers. The method by Jian(2005) termed as inpainting with Structure propagation follows a two-step process. In the first step, a user manually specifies important missing information in the hole by sketching object boundaries from the known to the unknown region

Figure 4. De-noising versus Inpainting: (a) Image corrupted by noise for de-noising application. (b) Damaged input image with missing region or "hole" for image inpainting
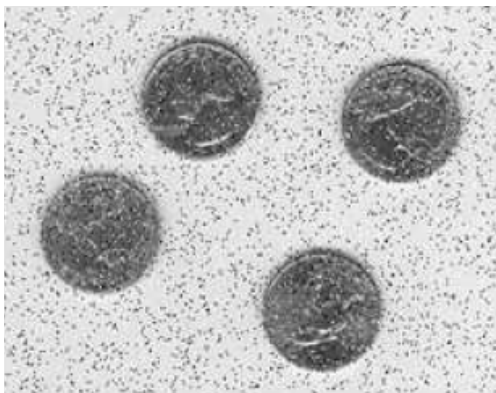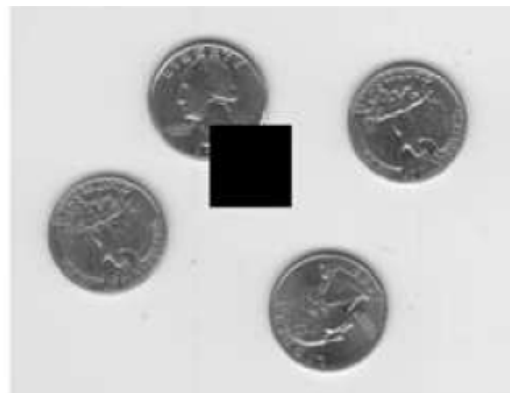
(a)   (b)

and then a tensor-based texture synthesis is used to generate the texture. The missing image patches are synthesized along the user specified curves by formulating the problem as a global optimization problem under various structural and consistency constraints.

Semi-automatic inpainting technique uses the concept of structure tensor. Since the structure tensor contains not only intensity information in a local area but also the predominant directions of the gradient in a specified neighborhood of one pixel and the degree to which these directions are coherent.

The filling priority is the product of the data term D (p) and the confidence term C (p), which can make the algorithm retain not only structure information but also texture information. The data term contains isophote structure information. The confidence term measures the reliable information around the pixel p needed inpainted.

The calculation function of the data item D(p) is the most critical point of the algorithm. The accurate estimation of the edge direction determines the value of the data item directly. If there is a lot of texture information at the edge of the image, it may lead to inaccurate estimation of the structure edge. So, we introduce structure tensor to improve the calculation method of D(p) as eq. (1)

$$D\big(p\big) = div\big(J\nabla I\big(x,y\big)\big) \tag{1}$$

Where, div is divergence operator.

The priority function is defined as the weight sum of regularized confidence term C(p) and new data term D(p) as eq. (2)

$$P\big(p\big) = aC_N\big(p\big) + \big(1-a\big)D\big(p\big) \tag{2}$$

Where, α is adjustment coefficient, satisfying 0<α<1.

Initially, select the target patch to be inpainted manually, extract the contour of the patch, and then repeat the following Steps until the inpainting is completed.

```
Algorithm for Semi-automatic inpainting:
1.  Determine the edge of the patch to be inpainted δΩ;
2.  Calculate CN (p), D (p) and P (p);
3.  Find the inpainting block with the highest priority;
4.  Search the image block  which is best matched with the current
block to be inpainted in the source patch of the image;
5.  Update the confidence term C (p) which has been filled;
```

Repeat the above steps in terms of iterations until the inpainting is completed. In our system, we have set the iteration value to 5000 for better result.

3.4.2 Fast Image Inpainting Technique

The Inpainting technique discussed in 3.4.1, usually requires several minutes to hours on current personal computers for the inpainting of relatively small areas. Such a time is unacceptable for interactive sessions and motivated us to design a simpler and faster algorithm capable of producing similar results in just a few seconds.

```
Algorithm of Fast Inpainting:
The whole process of image inpainting with Fast Digital Image
Inpainting approach could be stated as follows:
1. Read damaged image and its mask image.
2. Clear damaged area in the original damaged image.
3. Based neighborhoods, do isotropic diffusions inside of damaged
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area.
4. Keep step 3 until the result satisfies some desirable
condition.
5. Retrieve the result of step 4 and let it be the retrieval.
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   Discussing the above algorithm in detail as follows:

1.   Read damaged image and its mask image

   As we see below in Figure 5, the original image is damaged by an orange cross in the middle. Therefore, the area of orange cross is the damaged area and is required to restore. So, we use the orange cross image as our mask image.

2.   Clear Damaged Area in The Original Damaged Image

   Clearing damaged area means to remove all color information in the damaged area. Like what we did below in Figure 6, by removing all color information of the orange cross, the intensity of the cross area becomes 0.

3.   Based Neighborhoods, Do Isotropic Diffusions Inside of Damaged Area

   Keep all clear area of the original image and only do isotropic diffusion on damaged area. Following Figure shows the 1st iteration of isotropic diffusion on the area. We see the damaged area gets close to its neighborhoods.

4.   Keep Step 3 Until The Result Satisfies Some Desirable Condition

   Because the result is close to what we want but is still not close enough after 1 iteration; we need to apply more iteration.

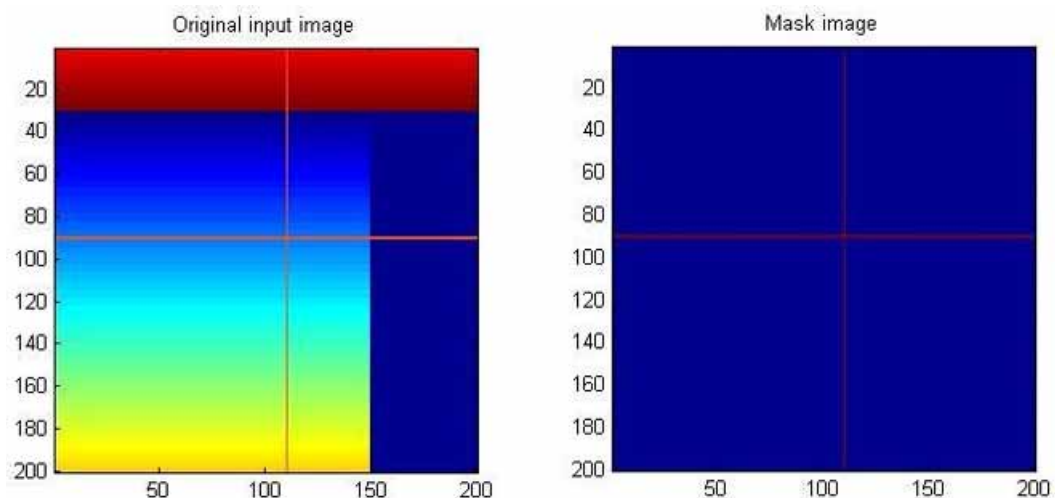Figure 5. Left: Original Image with Damage. Right: Masking of Original image

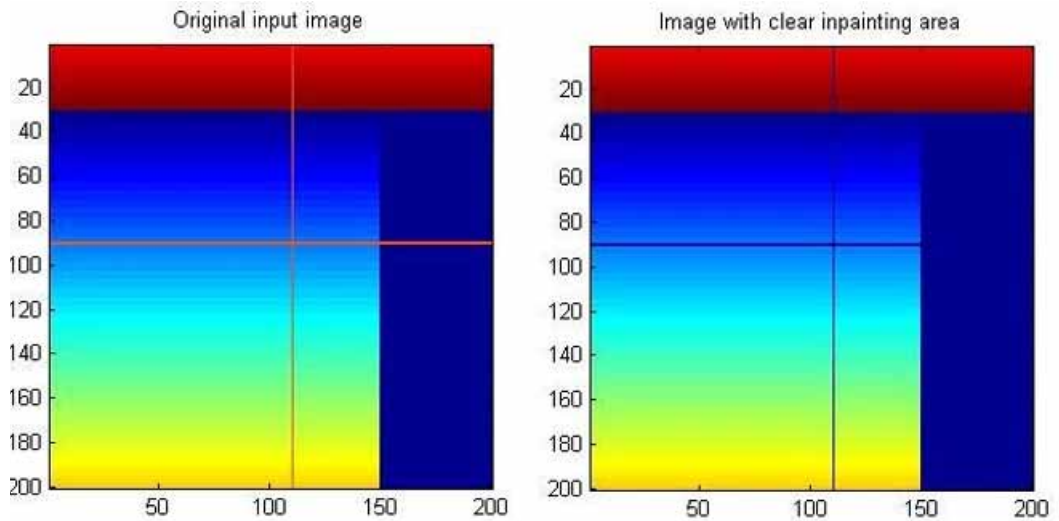**Figure 6. Left: Original Image. Right: Image with Clear Inpainting Area**

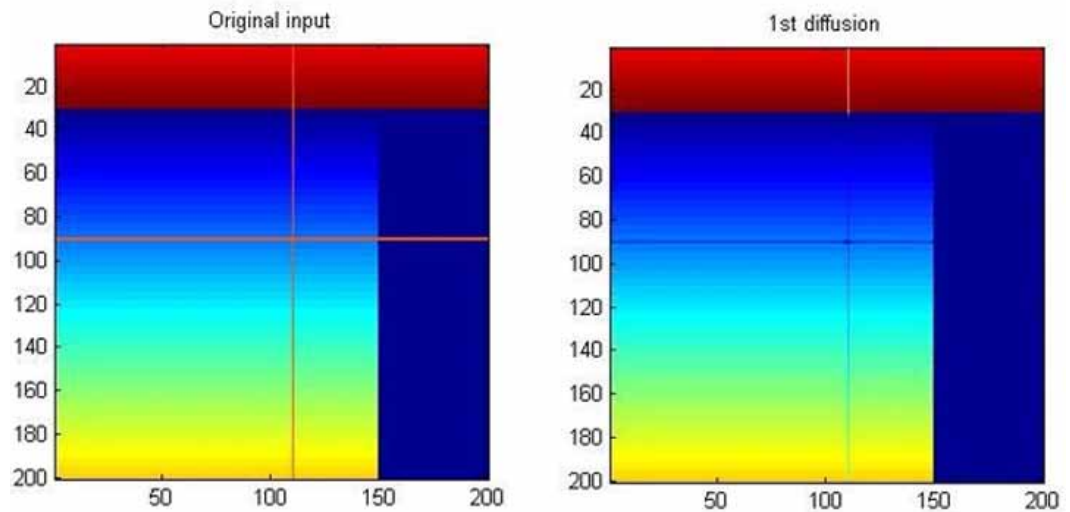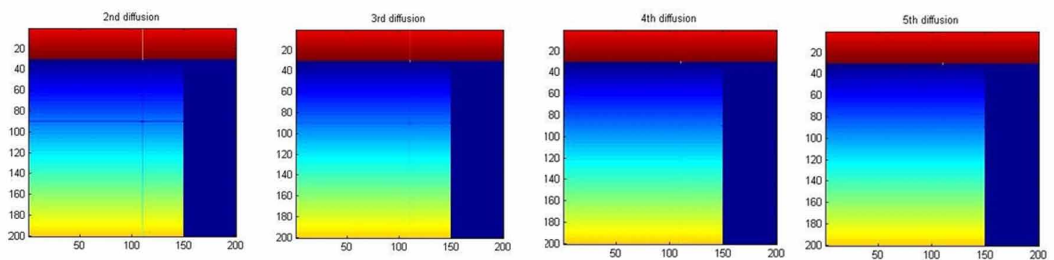**Figure 7. Left: Original Image. Right: Image with First Diffusion**

Figure 8. Left Image to Right Image with Second Diffusion to Fifth Diffusion

As we can see above, the damaged area gets closer and closer to its neighborhoods and finally after 5 iterations the area 'dissolves' itself in the whole image.

Here the desired condition is set to be $\left|M(n+1)-M(n)\right| < 10$, where M stands for the damaged area and n stands for the time of iterations.

5. Retrieve the Result of Step 4 And Let It Be The Retrieval

After we done step 4 and get a desired retrieval, we've done the inpainting procedure.
Unrecovered Area
Finally, Figure 9 shows the damaged image and its inpainting retrieval. We can see except for some singular pixel (pointed by orange arrow), the damaged image has been restored perfectly.

4. EXPERIMENTAL ANALYSIS AND RESULT

We used MATLAB a high-level technical computing language and interactive environment for image inpainting algorithm development.

4.1 Mathematical Analysis – Peak Signal to Noise Ratio (PSNR) & Mean Square Error (MSE)

PSNR is an important aspect for image quality assessment. The visual performance of a inpainted image can be studied under the analytical parameter such as MSE (Mean Square Error) and PSNR (Peak Signal to Noise Ratio) can be calculated as, eq. (3) and eq.(4) respectively. Let, $x_{i,j}$ be the original image and $x'_{i,j}$ be the frame whose dimensions are [M x N]. Then, Mean Square Error can be defined as

Figure 9. Left: Original Image with Damage Right: Image after applying Inpainting Algorithm
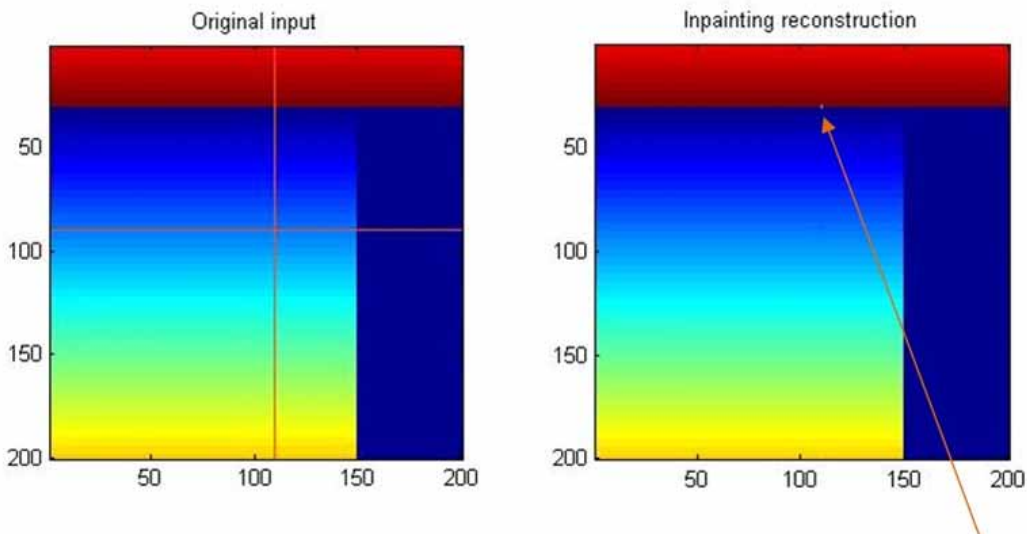
$$MSE = \frac{1}{MN} \sum_{i=1}^{M} \sum_{j=1}^{N} \left(x_{i,j} - x'_{i,j} \right)^2 \tag{3}$$

PSNR avoids many problems of measuring image quality by scaling the MSE according to the image range. It is defined by the equation

$$PSNR = 10\log \frac{255^2}{MSE} dB \tag{4}$$

Practically, for best result PSNR should be 25 to 35 dB.

However, the MSE and PSNR will be considered for further comparison, as they have been widely used for inpainting quality assessment (due to a lack of an effective objective metric).

Following Figure 10 shows the overall experimental flow chart of a proposed system operation. Mask region is generated on the selected image. Both the semi-Automatic and Fast image inpainting techniques are applied and restored the original image. Results obtained from both the techniques are compared by means of PSNR, MSE and timing constriants

4.2 Result: Image Retrieval Using Semi-Automatic Inpainting

4.2.1 Observational Result

Figure 11 shows the observational result for some selected images using semi-automatic inpainting technique. Figure 11(a) shows original image, Figure 11(b) shows inpainting region of an image, Figure 11(c) shows masked region of an image, Figure 11(d) shows restored image.

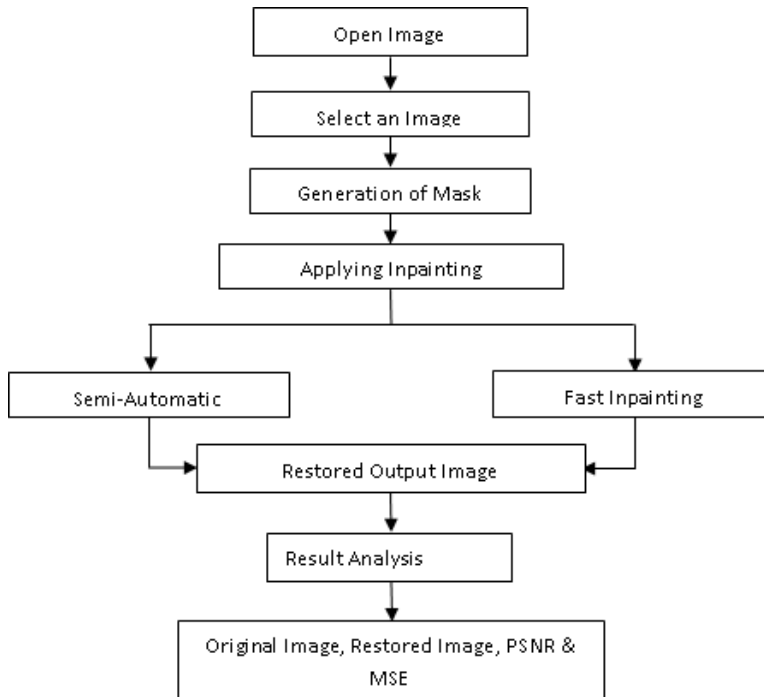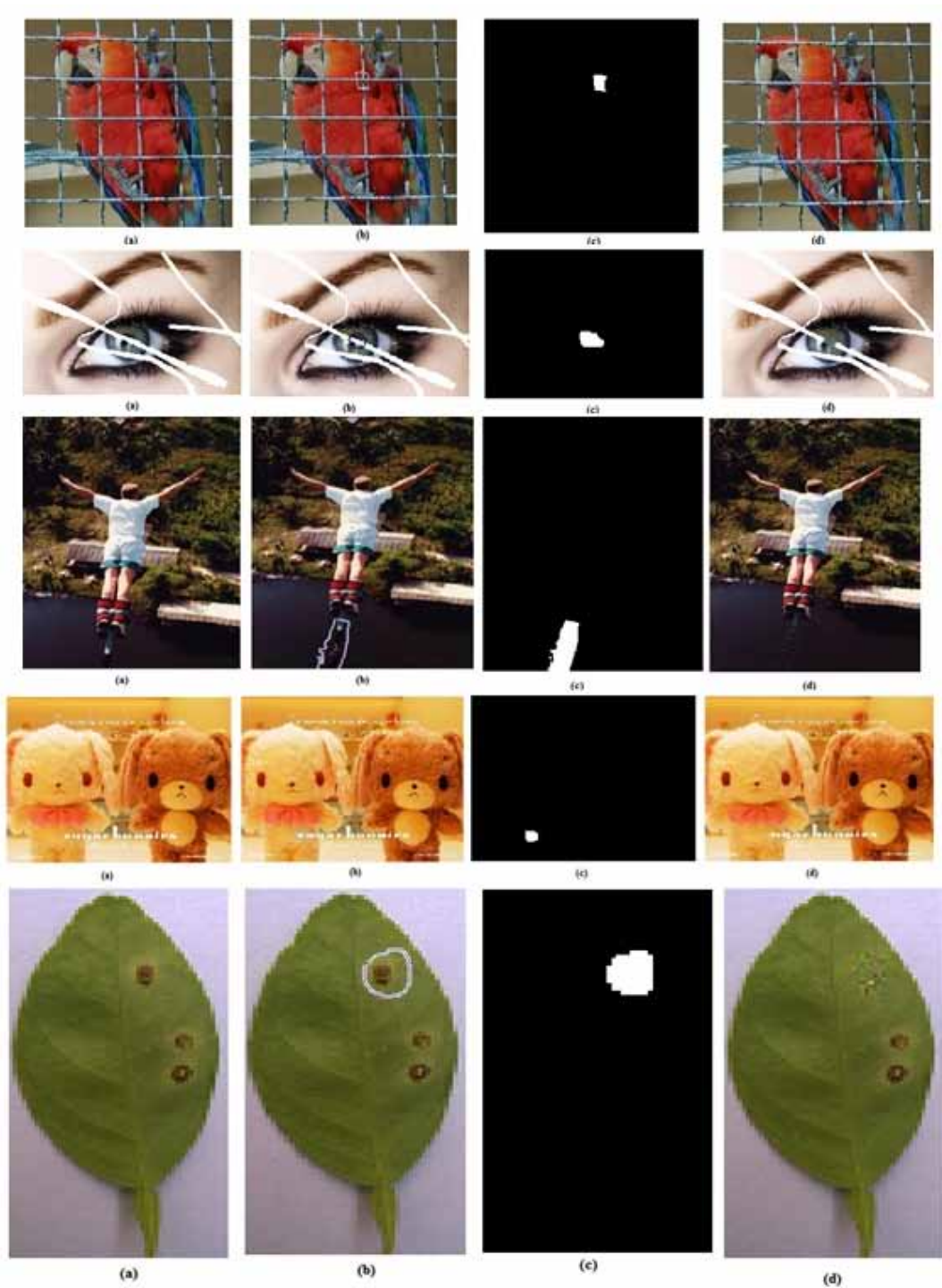**Figure 10. Overall experimental flow chart of proposed system**

Figure 11. (a) Original Image; (b) Inpainting Region; (c) Masked Region; (d) Restored image

4.2.2 Image Quality Assessments using Semi-automatic inpainting technique.

From the above table 1, PSNR parameter is quite good but time required for inpainting is very much large. For high resolution image requires more time while for low it takes somewhat small time for inpainting operation. Average results are also good as far as PSNR factor is concerned but not acceptable as of it requires much more time. And MSE is not so much good.

4.3 Result - Image Retrieval using Fast Inpainting

4.3.1 Observational Result

Figure 12 shows the observational result for some selected images using semi-automatic inpainting technique. Figure 12(a) shows original image, Figure 12(b) shows inpainting region of an image, Figure 12(c) shows masked region of an image, Figure 12(d) shows restored image.

4.3.2 Image Quality Assessment using Fast Inpainting

From the above table 2, PSNR parameter is quite good also the time required for inpainting is very much small as compared with semi-automatic inpainting. Again, as per the resolution of an image is concerned, for high resolution image requires more time while for low it takes somewhat small time for inpainting operation. Average results are also good as far as PSNR factor is concerned compared with semi-automatic inpainting. Average MSE is somewhat large. Average timing required for fast inpainting is negligibly small as compared with semi-automatic inpainting.

4.4 Average Result: Success Rate

Table 3 shows the success rate of our project using semi-automatic and fast image inpainting retrieval.

4.4.1 Statistical Graph: Timing Constraints

The above Figure 13 shows the statistical timing constraints graph in which Fast inpainting timing is very very smaller than Semi-automatic inpainting technique.

5. CONCLUSION

As the implementation of a presented system is computationally very much simple and less time consuming. It does not require complex hardware setup, as the speed of operation depends on higher configuration of a hardware processor. The restored images shows the better visual performance which are statistically justified using image quality assessment parameters such as Peak Signal-to-Noise Ratio (PSNR), Mean Square Error (MSE) as well as timing constraints. From the result analysis, we can conclude that the time requirement for Fast inpainting is very much small than Semi-automatic

Table 1. Image Quality Assessments and timing constraints for semi-automatic inpainting

Sr. No.	Input Image	Size	PSNR, dB	MSE	Time, sec.
1	Parrot	495x498	33.15	15.12	3636.58
2	Eye	241x159	28.27	57.73	627.11
3	Bungi man	206x308	34.54	18.96	842.344
4	Teddy	600x450	36.89	16.45	4849.97
5	Citrus Canker	50x100	33.13	11.87	42.21
Average			**33.196**	**26.78**	**2047.48**

Figure 12. (a) Original Image; (b) Inpainting Region; (c) Masked Region; (d) Restored Image
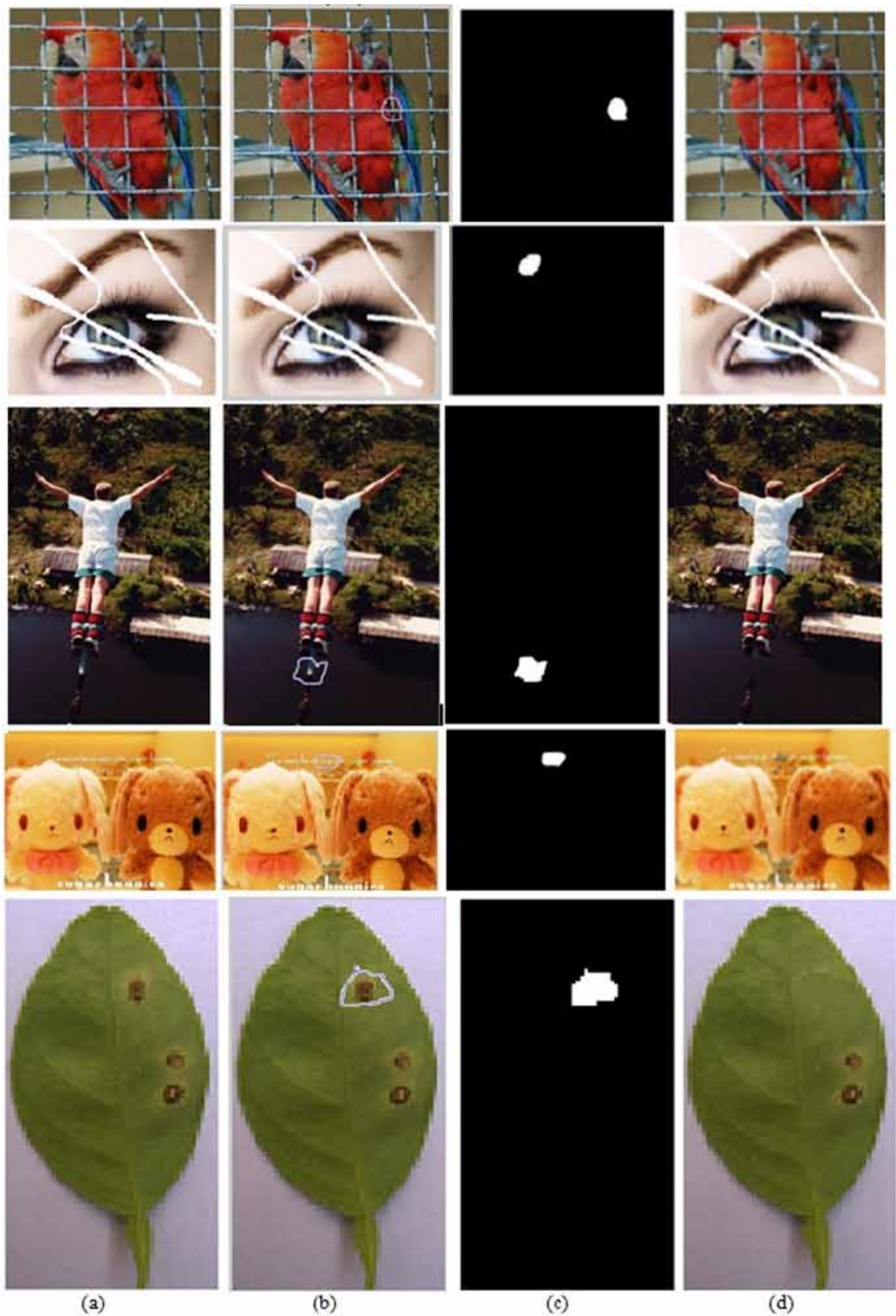
Table 2. Image Quality Assessments and timing constraints for Fast-automatic inpainting

Sr. No.	Input Image	Size	PSNR, dB	MSE	Time,sec.
1	Parrot	495x498	32.24	38.74	270.27
2	Eye	241x159	28.97	82.33	43.41
3	Bungi man	206x308	39.2	7.8	13.49
4	Teddy	600x450	35.37	18.87	57.1
5	Citrus Canker	50x100	40.03	6.45	5.87
Average			**35.162**	**30.838**	**78.028**

Table 3. Average Result of PSNR, MSE, Timing for Semi-automatic and Fast image inpainting

Sr. No.	Inpainting Tech.	PSNR, DB	MSE	Time, Sec.
1	Semi-automatic	33.196	26.78	2047.48
2	Fast	35.162	30.83	78.028

Figure 13. Statistical Graph: Timing Constraints
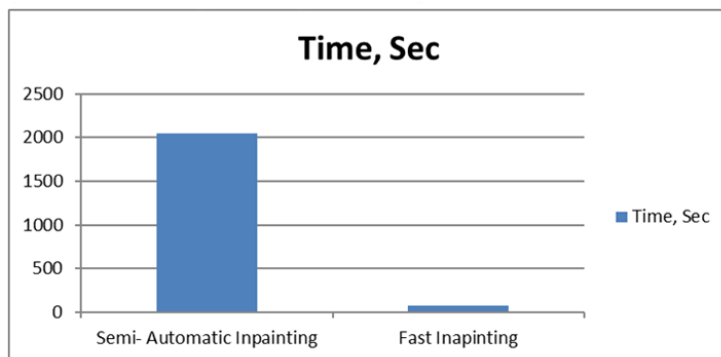
inpainting technique. Again, for high resolution image inpainting process takes much more time for result.

For larger inpainting domains, a scale-space filtering can be used to preserve the algorithm's reconstruction quality but the retrieval timing depends upon the overall scratches or damages located over the image i.e., for large areas damage requires more time for retrieval which is ultimately based on pixel neighborhood operation.

6. FUTURE SCOPE AND DISCUSSION

In the course of the research carried out in this paper, a number of possible directions for further research have been identiðed. Development of high-resolution image inpainting approach, image quality evaluation specifically focused on ðnding a metric that does not depend on a reference image and that correlates better with perceived quality, large area image inpainting is a challenging task to restore larger area damaged portion of an input image with the same performance success of smaller

area image retrieval. In future, just by modifying the presented inpainting technique, this concept can extend for video image inpainting multimedia approaches.

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