
Origin of Image Inpainting

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Abstract

Old Photographs, paintings, monuments etc are of great importance to mankind. They form our cultural heritage. These are not only artistic works but also give an insight into the evolution of culture, society generation etc. They are the gifts of previous generation to the present generation and hence are to be preserved. Even in personal life old photographs, old articles play an important role. With age, these tend to damage due to reasons like insect bite, shading, and the inevitable decay caused by weathering over a long period of time. Also, we inflict damages by mishandling, and negligence. In spite of adequate care, the damages occur. These damages are to be repaired to the original quality. The manual repair work so carried out maintaining the originality is Restoration.

Keywords: Photographs, restoration, painting, inpainting.

1. History of Painting

Ancient paintings can be classified into wall or mural paintings, canvas paintings, paper paintings, paintings on wood and ivory. Wall paintings [1] are the oldest known form of painting, dating back to the prehistoric paintings in the Altamira cave in Spain and the Lascaux Grotto in France. Damages of wall painting are due to moisture which may include drip staining, and delamination of paint layers due to efflorescence, water damage caused by leaking roofs, clogged drainpipes, and faulty plumbing. Lastly, another enemy of wall paintings is use of fossil fuels and automobile emissions, sulfur dioxide concentrations in the atmosphere.

In canvas painting, the canvas is fixed on wooden support and painting is done on canvas. This form of painting was popular in the 16th century [2]. It has been used largely in European and American painting traditions. The first paper painting was introduced during renaissance time. Both canvas and paper drawings are damaged due to aging, folding, insect bite, acidic condition, light and ultraviolet radiation from sun etc. In many cases, parts of the paint will lift from the surface, a condition called as blistering or scaling.

Painting on wood has been used from ancient Greece [3]. Wood has the disadvantage of swelling and shrinking across the grain when there are variations in the relative humidity of the atmosphere. Although paint has certain elasticity, it cannot usually take up much movement, and painting on wood generally cracks in a network referred to as 'craquelure' - repeated cracks. Ivory came into popular use as a painting support in the 18th and 19th centuries as part of miniature painting traditions largely based in Europe and the United States [4]. This naturally translucent material, ivory, derived from the tusks and large teeth of elephants, walrus and whales was well suited to the luminous techniques of painting. Ivory is composed of both organic and inorganic constituents of dentine. At lower levels of relative humidity, paintings on ivory desiccate, shrink, and crack. Light is another damaging agent and can be responsible for bleaching ivory surfaces.

All these types of art works are to be preserved, maintained and protected from damages and deteriorations. In spite of the adequate care damages are inflicted on these rare pieces of artwork. The repair or renovation of artwork of these damaged paintings has to be done with appropriate color by professional painters. This art and technique of repairing is restoration or inpainting. The techniques and methods of art preservation, conservation and restoration go hand in hand. Inpainting has become increasingly important aspect of the work of not only museums but also of civic authorities and of all those concerned with works of art, whether artists, collectors, or gallery goers.

2. Restoration to Inpainting

The manual repair of ancient artwork, paintings or photographs by professional and experienced experts is restoration. It is an art as well as science. The old photographs and artistic paintings are preserved for many years. While preserving, they are damaged due to age, dust, insect bite and develop scratches and cracks due to handling and folding. These damages are to be restored by either repairing or removing these damaged regions by suitable filling. Generally, from the knowledge of global information of painting, painter fills in the damaged region with an appropriate colors and fine brushes such that restored painting is almost original.

Restoration work received prominence in early 15th century in Europe as there was a lot of activity and interest in art and literature. Over the years, restoration artists brought old damaged paintings back close-to-the-original state. Artwork of middle ages was in need of restoration towards the end of the period of European history, as noted by Emile in [5]. At the beginning of the Renaissance era, the main concern regarding medieval artwork was to bring it up to date, by reconstructing missing or deteriorated parts of a painting or artistic photographs, by filling in with visually pleasing content [6]. Thus, the practice of filling-in damage region and making modifications to paintings in a non detectable way to an observer who looks at the restored work of art, without knowing the original damaged painting is called restoration. Its desired outcome is to make a damaged artwork more perceptible, while restoring its unanimity.

Restoration Procedure

Manual restoration is different for each artwork and each professional. There is no such thing as the way to solve the problem, but the underlying methodology is as follows:

1. The global picture and surrounding area of damaged region determines how to fill in the damaged region, the purpose of inpainting being to restore the unity of the work.
2. The damaged region is filled by same color as that of the surrounding region.
3. The small scratches and spots are painted by fine brush using color which matches to surrounding region.
4. While filling the texture, extra care is taken in repeating the same patterns.

Examples of a restoration of old damaged artistic photographs are shown in Figure 1 & 2.

Limitation of restoration/manual inpainting: Manual inpainting is subjective in nature, we need trained and professional expert restorers. The manual inpainting may produce good results with lot of fine tuning with heavy labor work and time., Getting perfect matching color is very difficult, since in ancient period color was prepared by flowers of different trees and each flower

gives a particular color. If these colors don't match perfectly with the global information of photograph, then it affects the quality of painting. After completing the painting of damaged region, the restorer comes to know the quality of inpainting. If he feels, that the chosen paint is incorrect or something is wrong during painting, then it is impossible to correct it, and whole artwork is lost and wasted.

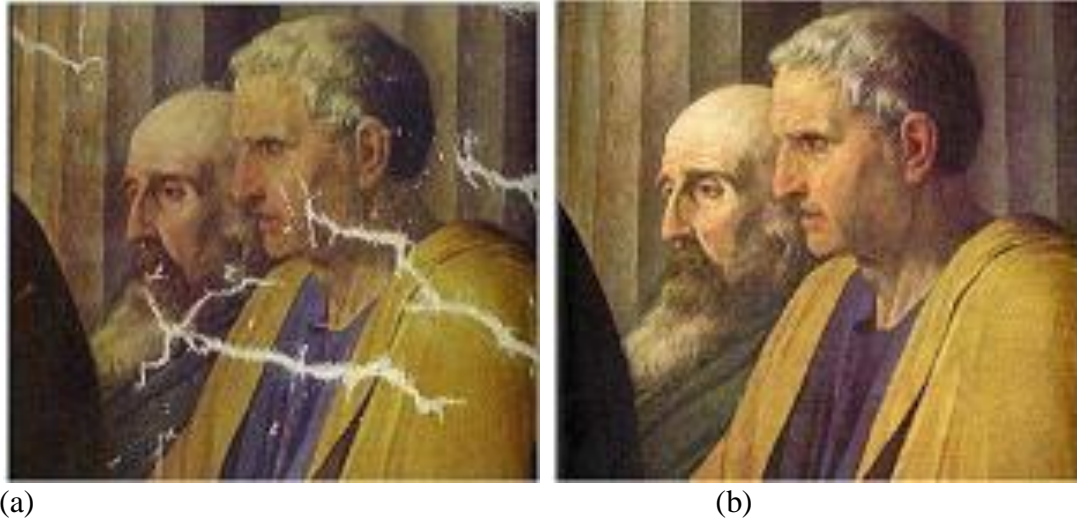


Figure 1 Manual inpainting of ancient photograph (a): Damaged photograph. (b): Manually restored photograph. *Courtesy* [5]



Figure 2 Manual inpainting of ancient photograph of girl with rabbit. (a): Damaged image. (b): Manually restored image. *Courtesy* of www.topcstudio.com.

Digital inpainting has beats the limitation of manual inpainting and has many advantages and many other applications apart from restoration. For example, superimposed text can be removed and the image buried behind the text can be recovered by digital image inpainting. The widespread use of computers and advances in the digital technology, inpainting using computers has received greater importance. In the year 2000 Bertalmio's coined the word 'inpainting' to the

restoration work of digital images using computers and proposed a digital inpainting algorithm [7]. Since then the image inpainting gathered momentum, and lot of research is being carried out.

3 Advantages of Digital Image Inpainting

Professional restorers filled the damage region using appropriate colors and brushes to restore traditional photographs and painting. They painted over lines and cracks. It needs a good eye, lot of concentration, patience, time and years of practice to match colors and texture and patience. Such a restoration work is irreversible.

With the birth of digital computer and advancement in science and technology, the digital inpainting was invented and introduced. A program is written for an algorithm, prepared by professional restorers and it is executed by computers to inpaint digital image. The computer can remove spots, lines, stains present in the image. Use of computer and associated program, inpaint is faster and cheaper than hiring a professional image restorer. The inpainting is in digital domain and hence is in some sense reversible. The original artwork is never restored unless the digital inpainting results are satisfactory. Also, for small damaged region (spot or crack) manual inpainting produces good results, for large regions painted region look like a patch. This can be avoided using digital inpainting. In addition, the superimposed text on an image, which is nearly impossible by manual inpainting, can be removed effectively using digital image inpainting. Conservation of manual restored images is uneconomical, whereas it is very easy to store digital inpainted image using memory. Since cost of memory less, hence same data can be replicated and stored in another memory.

Prerequisite process of digital inpainting is acquisition of the images. Image sensors are used to acquire and these acquired images are stored as digital images in the memory. Using digital inpainting techniques, damaged portions are filled-in and restored them in memory. In following section, we discuss image acquisition and image representation.

4. Image Acquisition and Digital Image Representation

In order to introduce digital inpainting, one need to know about how to acquire an image and convert into digital format. An image sensor (camera/scanner) is used to acquire the image. Analog to digital conversion is used for converting images to digital domain and is accomplished by sampling and quantization processes. The number of quantization levels describes the depth of color and intensity.

4.1 Image sensor

Image is acquired by the image sensor, which converts light into electrical signal. This process is known as image acquisition. The image acquisition process consists of four steps-

1. Illuminating an object or scene
2. Energy Reflected from the object or scene
3. Optical System to focus reflected light energy
4. Sensor to measure reflected energy

To acquire an image we need some kind of an energy source to illuminate the scene. In Figure 3 the sun acts as the natural energy source. The light reflected from the objects of interest is focused by some optics and is to be recorded in digital format. One of the main ingredients of the optical system is the lens. A lens is basically a piece of glass which focuses the incoming light onto the sensor.

Image sensor is used to record light falling by converting it into proportional electrical signal. An image sensor consists of a two dimensional array of cells as shown in Figure 4. The cell is capable of measuring the amount of incident light and converting it into voltage corresponding to the intensity of incident light on it. The cell denotes a pixel and it is the smallest area of the object being imaged. The density of the pixels corresponds to the resolution of an image. The voltage distribution corresponding to complete 2D array cell represents a continuous image $f(x, y)$. The value or amplitude f at spatial coordinates (x, y) is the voltage corresponding to the intensity of incident light at the coordinates (x, y) of 2D array.

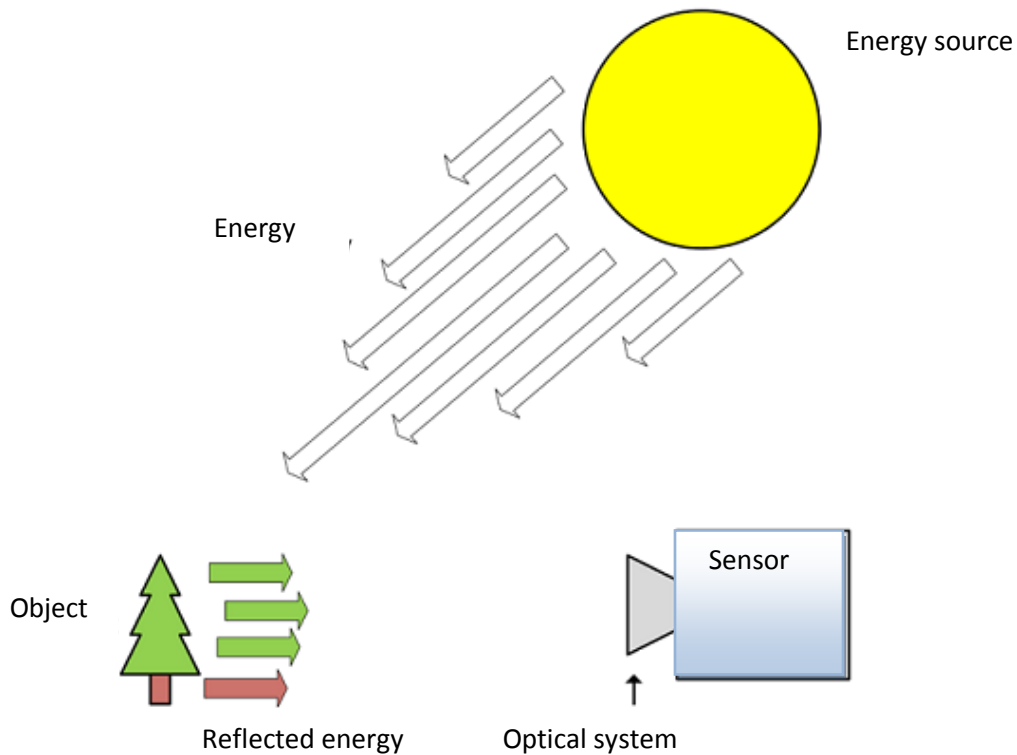


Figure 3 Overview of the typical image acquisition process, with the sun as light source, a tree as object and optical system and sensor to capture the image.

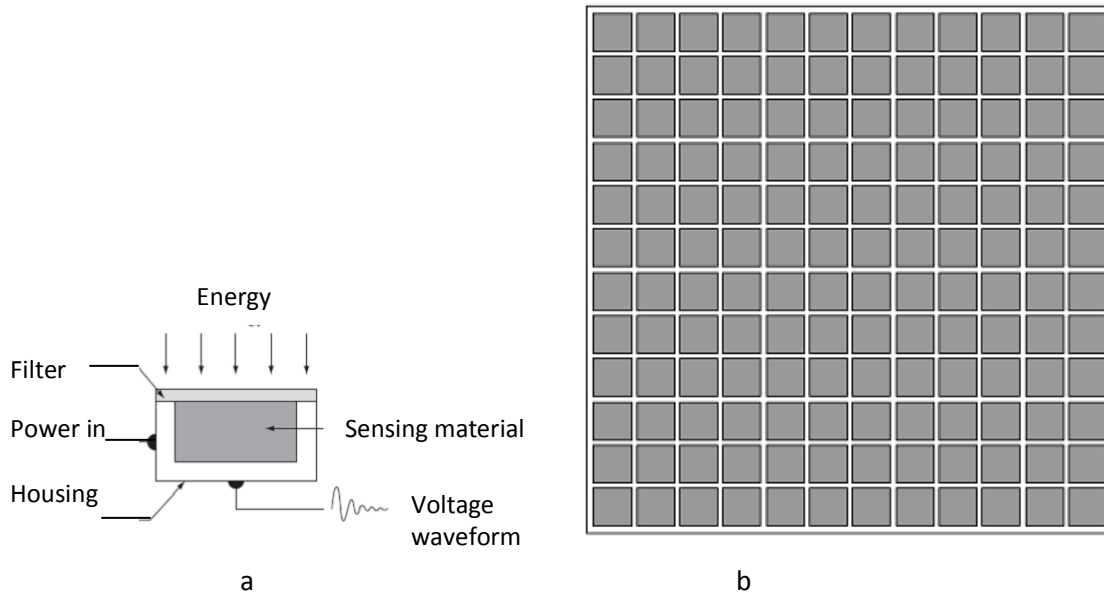


Figure 4 Image sensors. (a): Single cell. (b): Two dimension array of cell.

Types of Image Sensors

There are two types of image sensors, Charge Coupled Device (CCD) sensors and Complementary Metal Oxide Semiconductor (CMOS) sensors.

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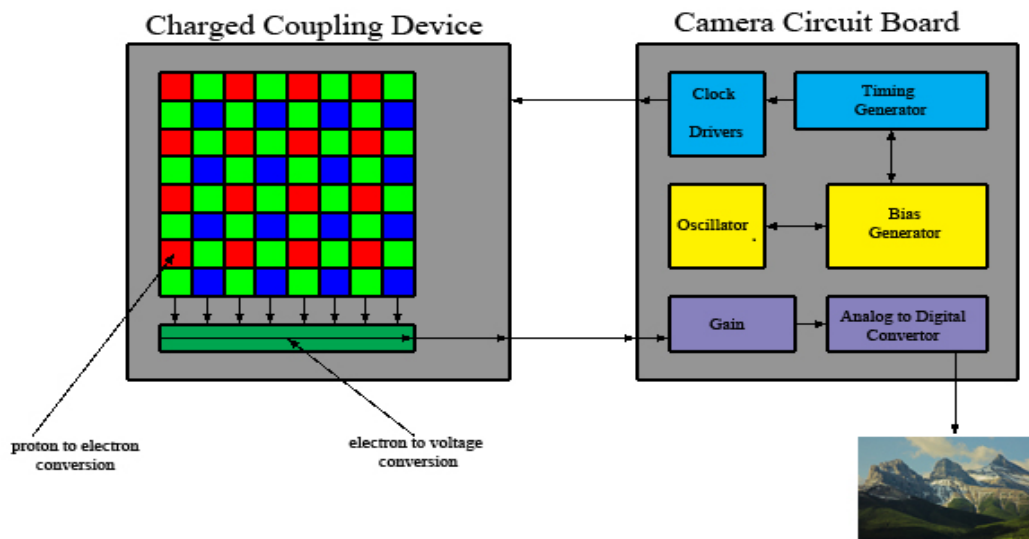


Figure 5 Block diagram of CCD sensor used in digital camera. *Courtesy* sensorcleaning.com

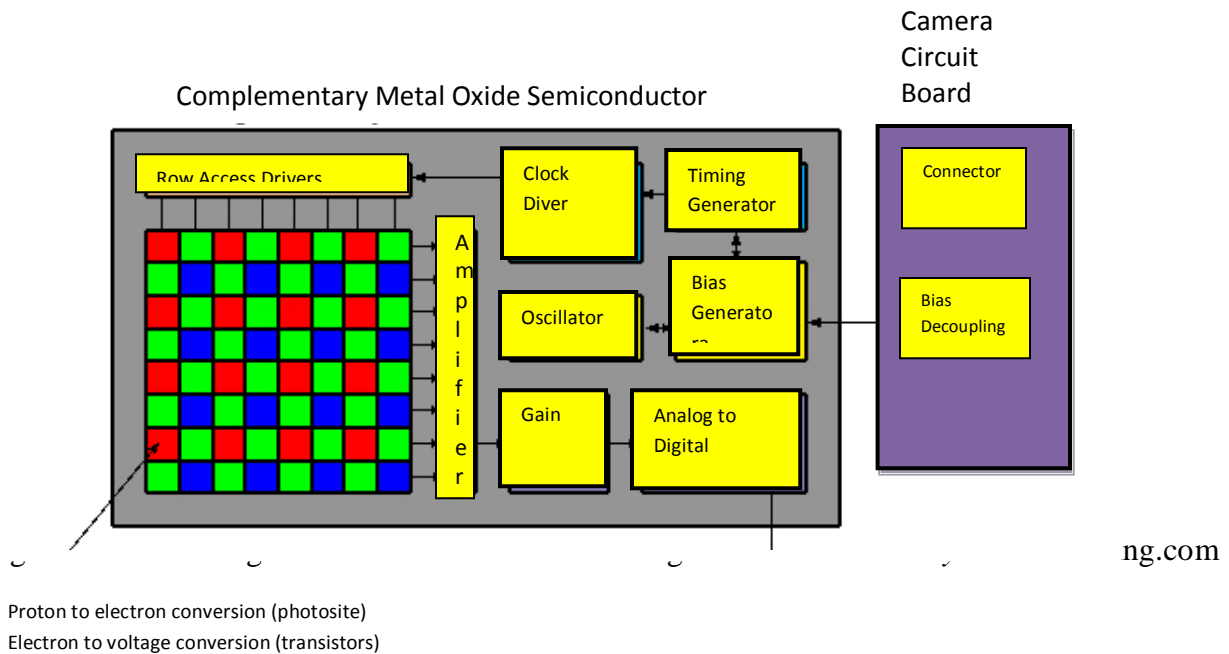


Figure 5 Block diagram of CMOS sensor used in digital camera.

Figure 6 Block diagram of CMOS sensor used in digital camera.

CCD sensors are widely used in digital cameras and other light sensing instruments. CCD sensors derive their name from how the charge is read after an image is captured. CCD array is manufactured with a broad range of sensing properties and is packaged in a rugged array of 4000 x 4000 elements or more. The response of each sensor is proportional to the integral of the light energy projected onto the surface of the sensor.

The first row of the array is read into an output register, which in turn is fed to an amplifier and an analog to digital converter as shown in Figure 5. After the first row has been read, it is dumped from the read out register and the next row of the array is read into the register. The charges of each row are 'coupled' so as each row moves down and out, the successive rows follow in turn. The digital data is then stored as a file that can be viewed and manipulated.

CMOS sensors or Active Pixel sensors are cut from a CMOS wafer which is cheaper to produce than a CCD wafer. CMOS sensors can potentially be implemented with fewer components, uses less power and provides data faster than CCDs. CMOS-based camera can be significantly smaller than a CCD camera. The Figure 6 shows the block diagram of CMOS sensor with associated components used in a digital camera.

Sony provides an extensive range of CCD and CMOS sensors suitable for applications such as entertainment, industrial, security and medical imaging. Sony is well known for the highest quality levels and know-how in CCD and CMOS production and now has the biggest market share on CCD sensors worldwide. Figure 7a – 7d shows the sensors manufactured by the Sony, Aptina's, Viimagic and Photonfocus companies.

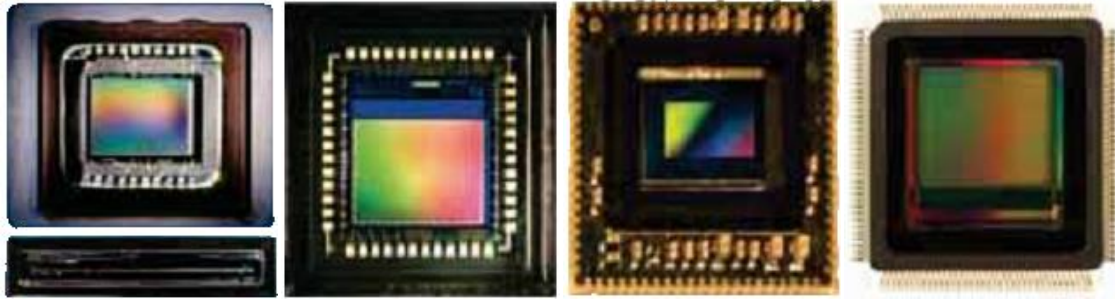


Figure 7 Image sensor manufactured by (a): sony. (b): Aptina's. (c): Viimagic. (d):Photonfocus.

4.2 Digital Image

An image captured by the sensor is expressed as a continuous function $f(x, y)$. It is a function of two independent spatial variables x and y with f as the amplitude of the image intensity at the spatial coordinate position (x, y) . In continuous image both amplitude and spatial coordinates take continuous values. The conversion of continuous image $f(x, y)$ into discrete data of two dimensional arrays $f(i, j)$ is called digitization. The digitization is accomplished by the process of sampling and quantization. Both processes are carried out by analog to digital converter in a digital camera.

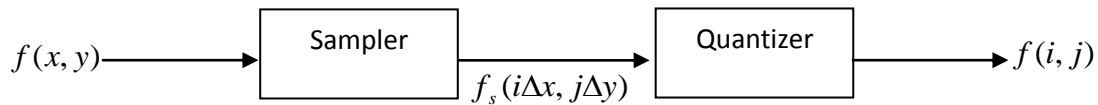


Figure 8 Block diagram of a digitizer, A to D Conversion of continuous image to digital image.

5 Digital Image Inpainting

Bertalmio's proposed the first digital inpainting technique [7] and coined the word 'inpainting' to the restoration work of digital images. Digital image inpainting is an interesting research topic and gathered much needed momentum since then. In the present context, images mean digital images and inpainting means digital inpainting. Thus image inpainting is the technique of filling-in damaged regions by the surrounding information without affecting the contents and quality i.e. restoration of an image using computers.

Definition: Digital image inpainting is a technique of repairing the damaged region by filling in with a set of new pixel such that the overall information content in the image is not altered.

The inpainting process can be described as introduction of new paint into and limited to areas of loss in the original paint layer in order to restore design continuity. The inpainting aims to complete damaged region by inserting best matching set of pixels into it such that inpainted image looks like the 'original image'. The completion of the area can be done by diffusing neighborhood pixels or by searching best matching patch in the image and pasting it in damaged region. The user selects an area to be inpainted and the inpainting algorithm automatically fills-in the region with information (pixels) derived from the local neighborhood or from global search

of entire image maintaining the best possible overall perceptual quality. The quality of the inpainting depends on the size of the damaged region, the geometry of the occluded objects, and the fill-in order etc. Small regions can be inpainted effortlessly, while large regions may produce unrealistic results.

Image may consist of structure or texture region or both. Hence we can broadly classify image inpainting techniques into two categories-

- *Structure inpainting*: The structure inpainting technique fills in the inpainting area with the surrounding information from a structured region. Generally, surrounding image pixels are diffused based on some criterion to inpaint.
- *Texture inpainting*: Texture inpainting techniques fills in the damaged regions using similar texture neighborhood in an image. They try to match statistics of damaged regions to statistics of known regions in neighborhood of a damaged region.

Image inpainting not only finds applications in restoration of old paintings, photographs removal of dust or stain marks of scanning glass on the scanned image or date but also can be applied to different areas like biomedical images to remove speckle, uncover image hidden behind super imposed text etc with novel and commercial importance.

The paper addresses the issues like removal of scratches, reconstruction of damaged portions and removal superimposed text, dates, and titles etc from images. Further, complete objects from a scene are removed by inpainting producing special effect (vanishing of an object). The objectionable or obscene contents can be removed from a scene or video. We envisage that there may be commercial value in blanking the certain portions or reconstruction of damaged portion of an image or streaming video in broadcasting. The infamous “airbrushing” of political enemies is a perfect example of inpainting.

Figure 9a shows biomedical endoscopic image and it can be inpainted to filter specular noise. The endoscopic images usually have a glossy appearance due to specular reflection of light source as shown in Figure 9a. Inpainting method alters the specular regions in a way that eliminates the negative effect of endoscopic image and gives visually pleasant result as shown in Figure 9b.

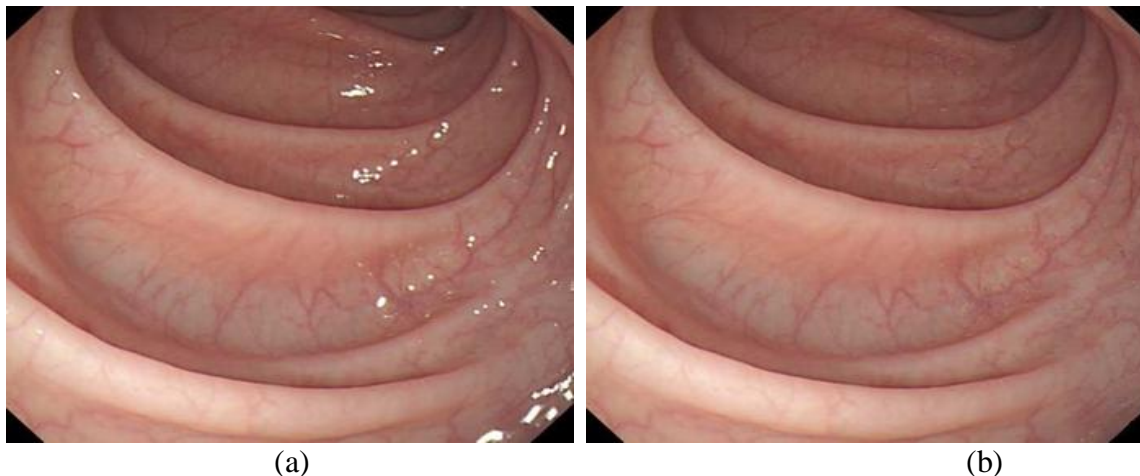


Figure 10 Inpainting of biomedical edoscopic image. (a) Original endoscopic image, *courtesy* [4]; (b) Inpainted image in which specular region is removed.

Inpainting may aid in archaeological restoration work. The old monuments develop cracks due to weathering, aging and other natural calamities. These cracks in old monuments can be inpainted as shown in Figure 11 which may help physical restoration work by providing possible appearance of the monument.

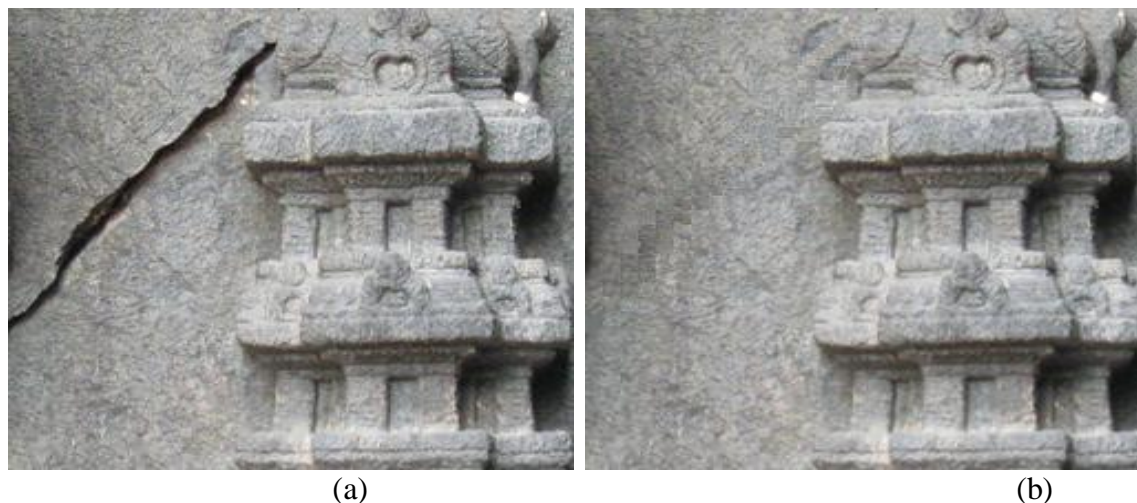


Figure 11 Wall of an old temple with a crack. (a): Archaeological texture image with a crack; (b) Possible restoration i.e. Crack is inpainted using maximum likelihood estimate.

References

- [1] Paolo Mora, Laura Mora and Paul Philppot. *Conservation of Wall Paintings*. Butterworths Series in Conservation and Museology, 1984.
- [2] David Bomford. *Conservation of Paintings*. National Gallery London, 1997.
- [3] Norman Brommelle, Anne Moncrieff and Perry Smith. *Conservation of Wood in Painting and the Decorative Arts*. London IIC, 1978.
- [4] Knut Nicolaus and Christine Westphal. *The Restoration of Paintings*. Konemann Publisher, 1999.
- [5] G. Emile-Male. *The Restorer's Handbook of Easel Painting*. Van Nostrand Reinhold, New York, 1976.
- [6] S. Walden. *The Ravished Image*. St. Martin's Press, New York, 1985.
- [7] M. Bertalmio, G. Sapiro, V. Caselles, and C. Ballester. *Image Inpainting*. Proceedings of SIGGRAPH. Computer Graphics Processing, 2000, pp 417-424.