Unit -1

Introduction to Image Processing

Image-

An image is defined as a two-dimensional function, F(x,y), where x and y are spatial coordinates, and the amplitude of F at any pair of coordinates (x,y) is called the intensity of that image at that point. When x,y, and amplitude values of F are finite, we call it a digital image.
In other words, an image can be defined by a two-dimensional array specifically arranged in rows and columns.
Digital Image is composed of a finite number of elements, each of which elements have a particular value at a particular location. These elements are referred to as *picture elements, image elements and pixels*. A *Pixel* is most widely used to denote the elements of a Digital Image.

Types of an image

1. BINARY IMAGE– The binary image as its name suggests, contain only two pixel elements i.e 0 & 1,where 0 refers to black and 1 refers to white. This image is also known as Monochrome.
2. BLACK AND WHITE IMAGE– The image which consist of only black and white color is called BLACK AND WHITE IMAGE.
3. 8 bit COLOR FORMAT– It is the most famous image format. It has 256 different shades of colors in it and commonly known as Grayscale Image. In this format, 0 stands for Black, and 255 stands for white, and 127 stands for gray.
4. 16 bit COLOR FORMAT– It is a color image format. It has 65,536 different colors in it.It is also known as High Color Format. In this format the distribution of color is not as same as Grayscale image.

A 16 bit format is actually divided into three further formats which are Red, Green and Blue. That famous RGB format.

Image Processing -

Image processing is a way to convert an image to a digital aspect and perform certain functions on it, in order to get an enhanced image or extract other useful information from it. It is a type of signal time when the input is an image, such as a video frame or image and output can be an image or features associated with that image. Usually, the AWS Image Processing system includes treating images as two equal symbols while using the set methods used.

It is one of the fastest growing technologies today, with its use in various business sectors. Graphic Design forms the core of the research space within the engineering and computer science industry as well. Image processing is a way by which an individual can enhance the quality of an image or gather alerting insights from an image and feed it to an algorithm to predict the later things.

Image processing basically involves the following three steps.

1. Importing an image with an optical scanner or digital photography.

2. Analysis and image management including data compression and image enhancement and visual detection patterns such as satellite imagery.

3. It produces the final stage where the result can be changed to an image or report based on image analysis.

Digital Image representation –

Image representation refers to how visual data is translated into a digital format that computers can interpret. It involves capturing information about the color, shape, texture, and other visual characteristics of an image and encoding them in a structured way. The chosen representation format determines how the image is stored, processed, and displayed.

Image representation is vital for image processing as it provides the foundation for subsequent analysis, manipulation, and interpretation of visual data. It allows us to extract meaningful information from images, identify patterns, recognize objects, and perform various tasks such as image compression, enhancement, and segmentation.

Accurate and efficient image representation is critical for ensuring reliable and consistent results in image processing algorithms. Choosing the right representation technique impacts the quality, speed, and effectiveness of image processing tasks.

The Role of Pixels in Image Representation

Pixels form the building blocks of image representation. They are the smallest individual units in a digital image and represent the discrete samples of color or intensity at specific coordinates. Depending on the image format, pixels store information about color channels (such as red, green, and blue), grayscale intensities, or other attributes.

The arrangement and values of pixels determine the overall appearance of an image. Image processing algorithms operate on these pixels, analyzing their values and relationships to achieve specific objectives. Understanding and correctly manipulating pixels are crucial for accurate image representation and successful image processing.

Two popular types of image representation formats are bitmap and vector.

Bitmap Representation

Bitmap representation, or raster representation, stores images as a grid of pixels, where each pixel corresponds to a specific color or intensity value. Bitmap images consist of a fixed number of pixels and have a resolution that determines the level of detail in the image. Common bitmap formats include JPEG, PNG, and GIF. They are well-suited for capturing and representing natural images but tend to be resolution-dependent and can suffer from pixelation when scaled up.

Vector Representation

Vector representation, on the other hand, uses mathematical descriptions of geometric shapes, lines, curves, and color attributes to represent an image. Instead of pixels, vector images use mathematical formulas to define the shapes and colors. Vector formats, such as SVG (Scalable Vector Graphics) and AI (Adobe Illustrator), are resolution-independent and can be resized without losing quality. They are ideal for graphics, illustrations, logos, and other types of images with distinct shapes and patterns.

Image representation is essential in image processing to enable efficient analysis and manipulation of visual data. Representation formats determine how images are stored, processed, and displayed by capturing and encoding image characteristics. Pixels are central to image representation, encoding color and intensity values and facilitating subsequent analysis.

Whether using bitmap representation for natural images or vector representation for graphic illustrations, understanding and employing the appropriate image representation technique is crucial for achieving accurate and effective image processing outcomes.

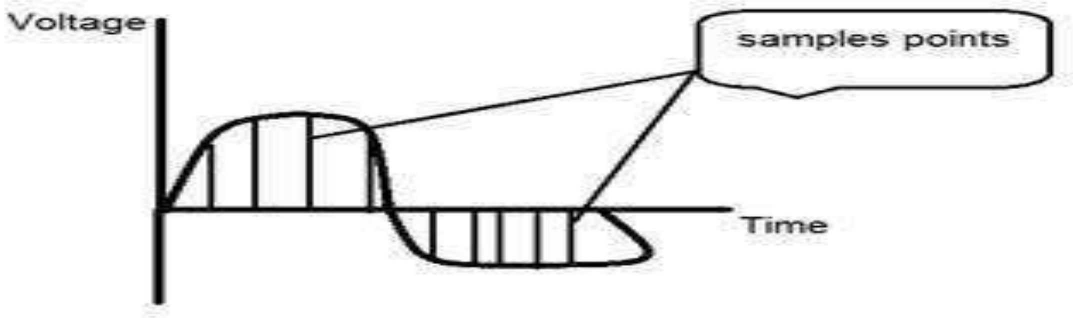
Sampling & Quantization –

Sampling-

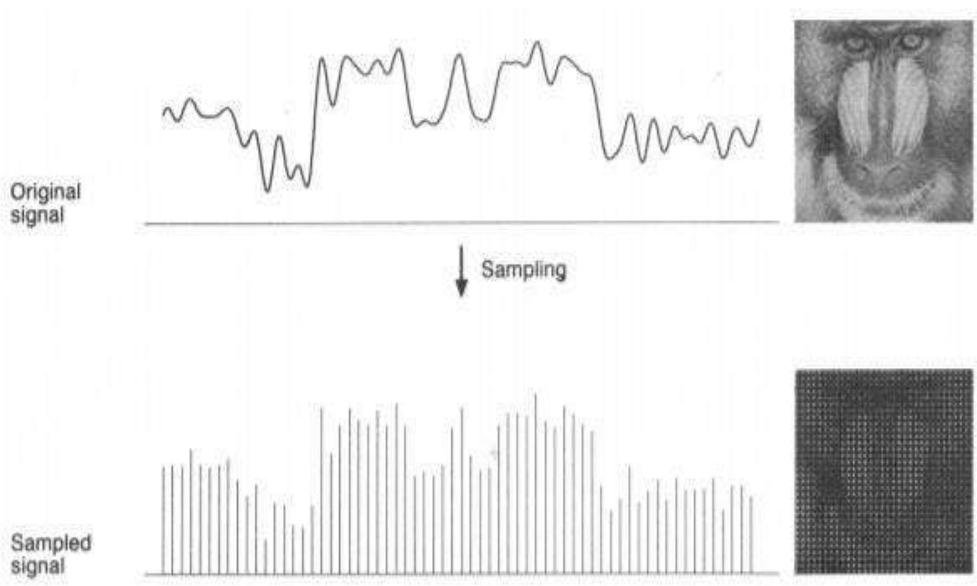
Image sampling is the process of converting a continuous image (analog) into a discrete image (digital) by selecting specific points from the continuous image. This involves measuring the image at regular intervals and recording the intensity (brightness) values at those points.

Since an analogue image is continuous not just in its co-ordinates (x axis), but also in its amplitude (y axis), so the part that deals with the digitizing of co-ordinates is known as sampling. In digitizing sampling is done on independent variable. In case of equation y = sin(x), it is done on x variable.

When looking at this image, we can see there are some random variations in the signal caused by noise. In sampling we reduce this noise by taking samples. It is obvious that more samples we take, the quality of the image would be more better, the noise would be more removed and same happens vice versa. However, if you take sampling on the x axis, the signal is not converted to digital format, unless you take sampling of the y-axis too which is known as quantization.



Sampling has a relationship with image pixels. The total number of pixels in an image can be calculated as Pixels = total no of rows * total no of columns. For example, let's say we have total of 36 pixels, that means we have a square image of 6X 6. As we know in sampling, that more samples eventually result in more pixels. So it means that of our continuous signal, we have taken 36 samples on x axis. That refers to 36 pixels of this image. Also the number sample is directly equal to the number of sensors. Here is an example for image sampling –



Advantages:

1. **Data Reduction:** Converts a continuous signal into a finite set of points, making storage and processing more manageable.
2. **Compatibility:** Sampled images are easily processed by digital systems and algorithms.

Disadvantages:

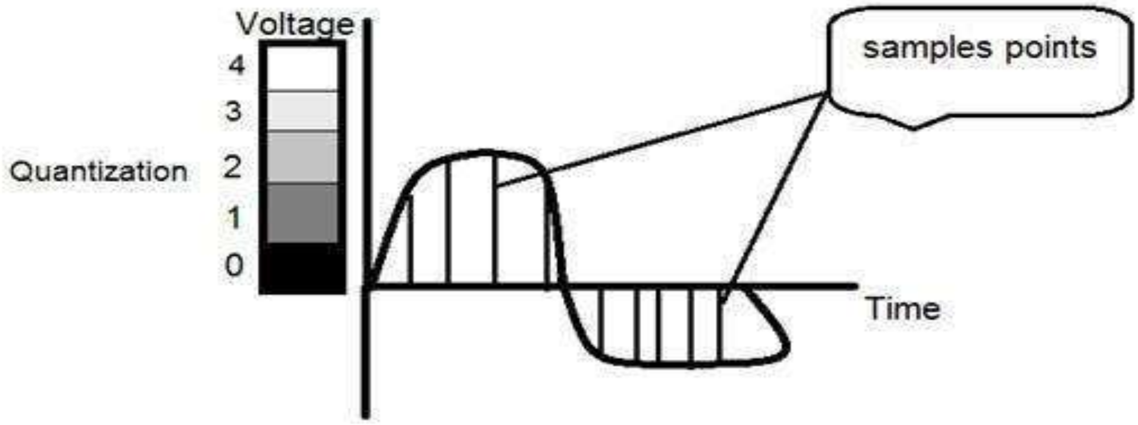
1. **Information Loss:** Inevitably loses some information by approximating a continuous signal

Quantization-

Image quantization is the process of converting the continuous range of pixel values (intensities) into a limited set of discrete values. This step follows sampling and reduces the precision of the sampled values to a manageable level for digital representation.

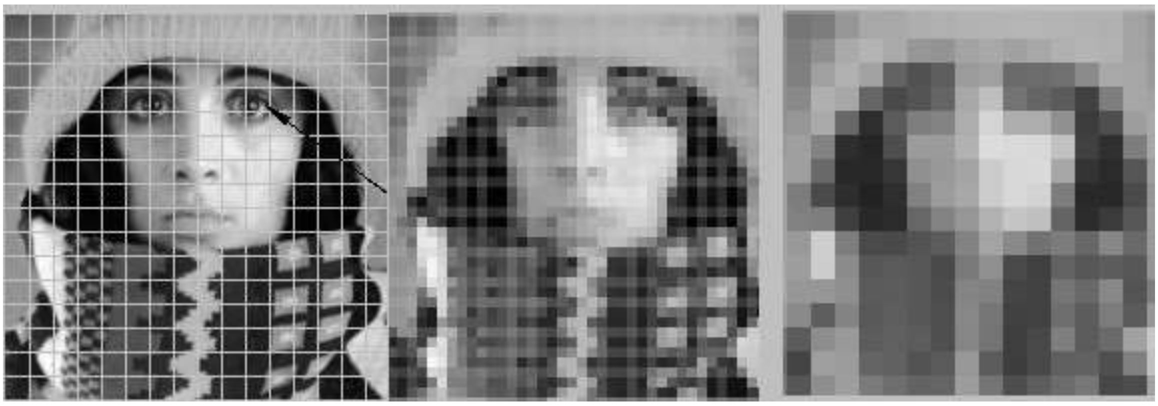
Quantization is opposite to sampling because it is done on "y axis" while sampling is done on "x axis". Quantization is a process of transforming a real valued sampled image to one taking only a finite number of distinct values. Under quantization process the amplitude values of the image are digitized. In simple words, when you are quantizing an image, you are actually dividing a signal into quanta(partitions).

Here we assign levels to the values generated by sampling process. In the image showed in sampling explanation, although the samples has been taken, but they were still spanning vertically to a continuous range of gray level values. In the image shown below, these vertically ranging values have been quantized into 5 different levels or partitions. Ranging from 0 black to 4 white. This level could vary according to the type of image you want.



There is a relationship between Quantization with gray level resolution. The above quantized image represents 5 different levels of gray and that means the image formed from this signal, would only have 5 different colors. It would be a black and white image more or less with some colors of gray.

When we want to improve the quality of image, we can increase the levels assign to the sampled image. If we increase this level to 256, it means we have a gray scale image. Whatever the level which we assign is called as the gray level. The number of quantization levels should be high enough for human perception of fine shading details in the image. The occurrence of false contours is the main problem in image which has been quantized with insufficient brightness levels. Here is an example for image quantization process.



Advantages:

1. **Data Compression:** Reduces the amount of data by limiting the number of possible values for each pixel.
2. **Simplified Processing:** Makes image processing operations simpler and faster with fewer distinct values.
3. **Noise Reduction:** Helps reduce the impact of noise by mapping small variations in intensity to the same value.

Disadvantages:

1. **Loss of Detail:** Reduces the range of colors or intensity levels, leading to a loss of fine detail and potential color banding.
2. **Quantization Error:** Introduces differences between the original and quantized values, which can become noticeable.
3. **Reduced Image Quality:** Overly aggressive quantization can significantly degrade image quality, making the image appear blocky.

Feature	Image Sampling	Image Quantization
Definition	Conversion of a continuous image into a discrete set of points by selecting specific pixel positions	Conversion of continuous pixel intensity values into discrete levels
Process Focus	Spatial information (locations of pixels)	Intensity values (brightness or color levels)
Outcome	A grid of pixel values representing spatial resolution	A set of discrete intensity values for each pixel
Resolution Aspect	Affects spatial resolution (detail and clarity of the image)	Affects color/gray level resolution (number of shades or colors)

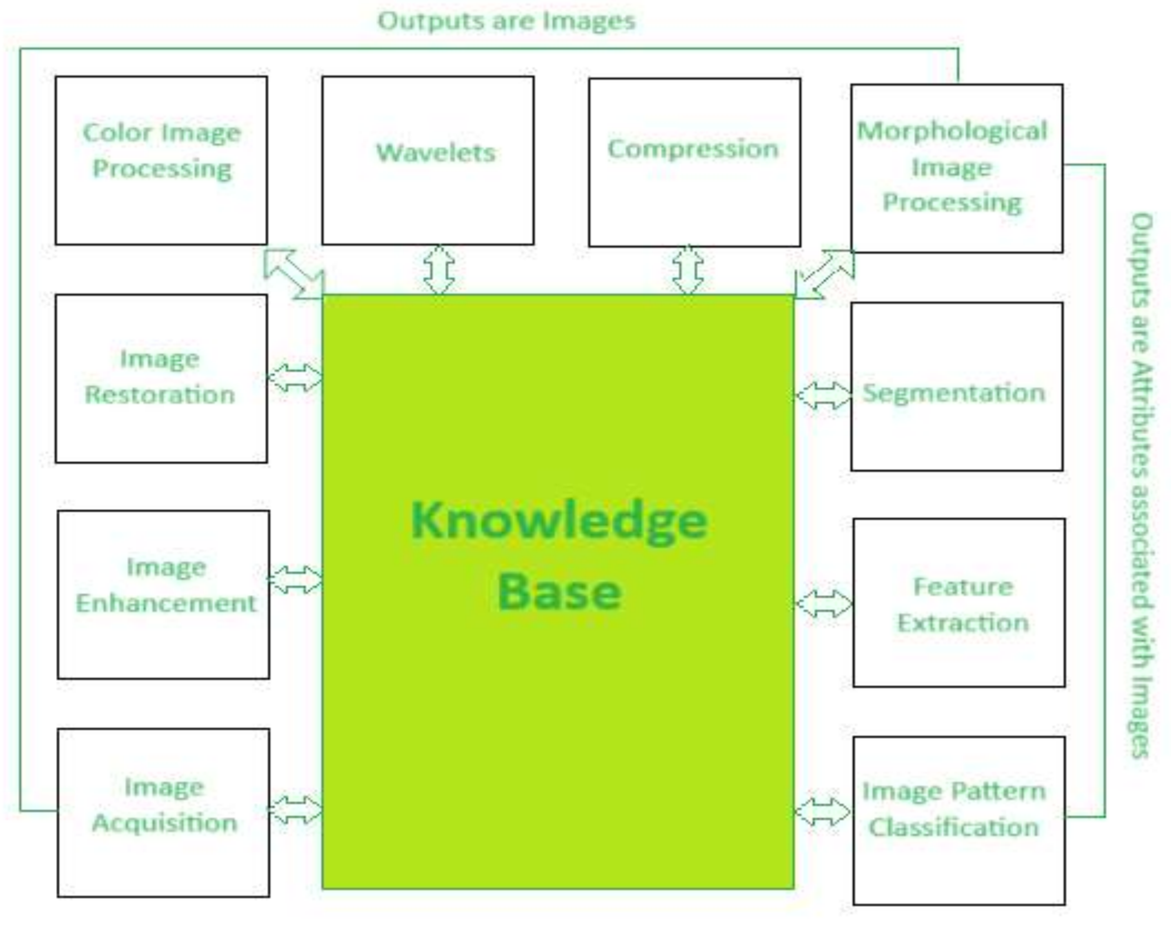
Digital Image Processing System -

Digital image processing uses to perform image processing on digital images to extract some useful information. Digital image processing has many advantages as compared to analog image processing. Wide range of algorithms can be applied to input data which can avoid problems such as noise and signal distortion during processing. As we know, images are defined in two dimensions, so DIP can be modeled in multidimensional systems.

Purpose of Image processing-

1. Visualization: The objects which are not visible, they are observed.
2. Image sharpening and restoration: It is used for better image resolution.
3. Measurement of pattern: In an image, all the objects are measured.
4. Image Recognition: Each object in an image can be distinguished.

Steps of Digital Image Processing-



1. Image Acquisition

Image acquisition is the first step of the fundamental steps of DIP. In this stage, an image is given in the digital form. Generally, in this stage, pre-processing such as scaling is done. we get the image in digital form. This is done using sensing materials like sensor strips and sensor arrays and electromagnetic wave light source. The light source falls on an object and it gets reflected or transmitted which gets captured by the sensing material. The sensor gives the output image in voltage waveform in response to electric power being supplied to it. The example of a situation where reflected light is captured is a visible light source. Whereas, in X-ray light sources transmitted light rays are captured.

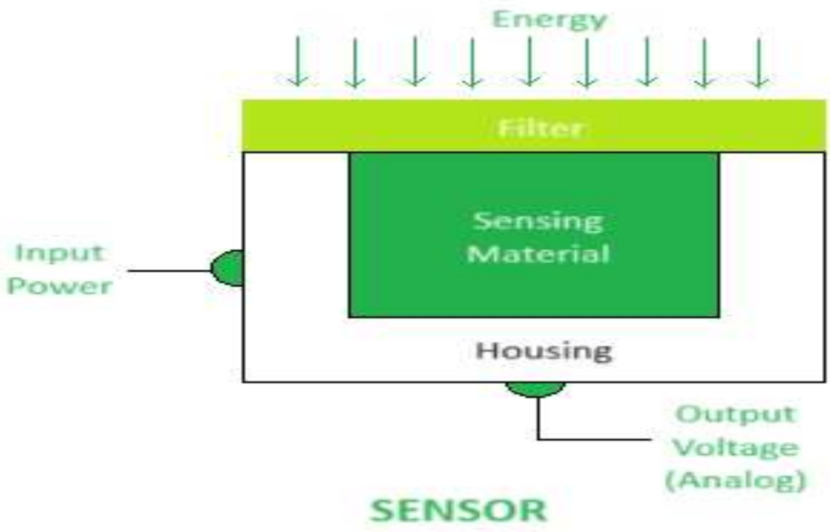
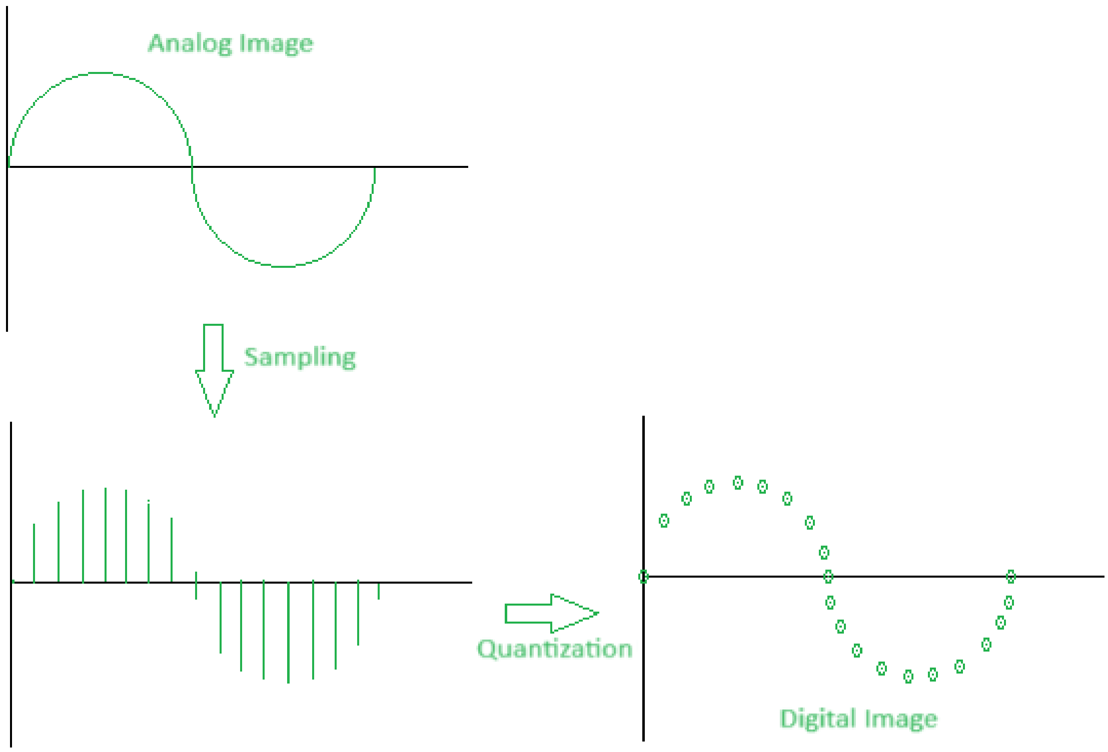


Image Acquisition

The image captured is analog image as the output is continuous. To digitise the image, we use sampling and quantization where discretize the image. Sampling is discretizing the image spatial coordinates whereas quantization is discretizing the image amplitude values.



Sampling and Quantization

2. Image Enhancement

Image enhancement is the simplest and most attractive area of DIP. In this stage details which are not known, or we can say that interesting features of an image is highlighted. Such as brightness, contrast, etc.

3. Image Restoration

Image restoration is related to improving an image. But image enhancement is more of a subjective step where image restoration is more of an objective step. Restoration is applied to a degraded image trying to recover back the original model. Here firstly we try to estimate the degradation model and then find the restored image.
We can estimate the degradation by observation, experimentation and mathematical modelling. Observation is used when you do not know anything about the setup of the image taken or the environment. In experimentation, we find the point spread function of an impulse with a similar setup. In mathematical modelling, we even consider the environment at which the image was taken and it is the best out of all the other three methods.

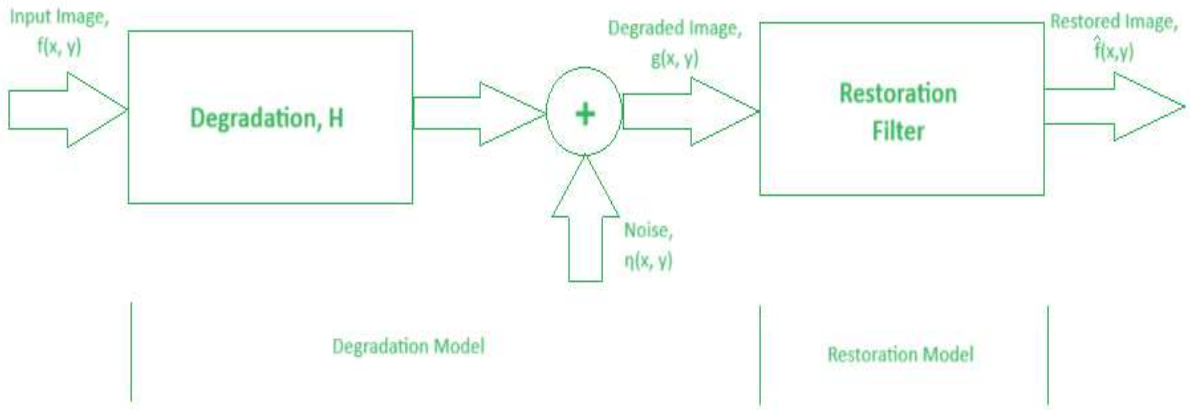


Image Restoration Block Diagram

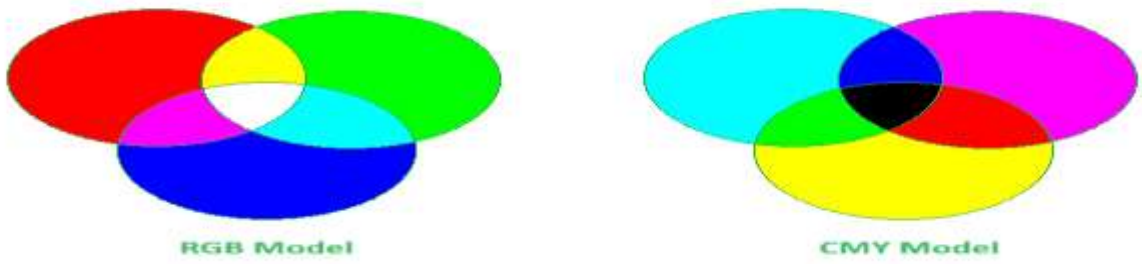
To find the restored image, we generally use one of the three filters - inverse filter, minimum mean square (weiner) filter, constrained least squares filter. Inverse filtering is the simplest method but cannot be used in presence of noise. In the Wiener filter, mean square error is minimised. In constrained least error filtering, we have a constraint and it is the best method.

4. Color Image Processing

Color image processing is a famous area because it has increased the use of digital images on the internet. This includes color modeling, processing in a digital domain, etc.

Colour image processing is motivated by the fact that using colour it is easier to classify and the human eye can easily see thousands of colours than shades of black and white. Colour image processing is divided into types - pseudo colour or reduced colour processing and full colour processing. In pseudo colour processing, the grey scale is applied to one colour. It was used earlier. Now-a-days, full colour processing is used for full colour sensors such as digital cameras or colour scanners as the price of full colour sensor hardware is reduced significantly.

There are various colour models like RGB (Red Green Blue), CMY (Cyan Magenta Yellow), HSI (Hue Saturation Intensity). Different colour models are used for different purposes. RGB is understandable for computer monitors. Whereas CMY is understandable for a computer printer. So there is an internal hardware which converts RGB to CMY and vice versa. But humans cannot understand RGB or CMY, they understand HSI.



Colour Models

5. Wavelets and Multi-Resolution Processing

In this stage, an image is represented in various degrees of resolution. Image is divided into smaller regions for data compression and for the pyramidal representation.

Wavelets represent an image in various degrees of resolution. It is one of the members of the class of linear transforms along with fourier, cosine, sine, Hartley, Slant, Haar, Walsh-Hadamard. Transforms are coefficients of linear expansion which decompose a function into a weighted sum of orthogonal or biorthogonal basis functions. All these transforms are reversible and interconvertible. All of them express the same information and energy. Hence all are equivalent. All the transforms vary in only the manner how the information is represented.

6. Compression

Compression is a technique which is used for reducing the requirement of storing an image. It is a very important stage because it is very necessary to compress data for internet use.

Compression deals with decreasing the storage required to the image information or the bandwidth required to transmit it. Compression technology has grown widely in this era. Many people are knowledgeable about it by common image extension JPEG (Joint Photographic Experts Group) which is a compression technology. This is done by removing redundancy and irrelevant data. In the encoding process of compression, the image goes through a series of stages - mapper, quantizer, symbol encoder. Mapper may be reversible or irreversible. Example of mapper is run length encoding. Quantizer reduces the accuracy and is an irreversible process. Symbol encoders assign small values to more frequent data and is a reversible process.

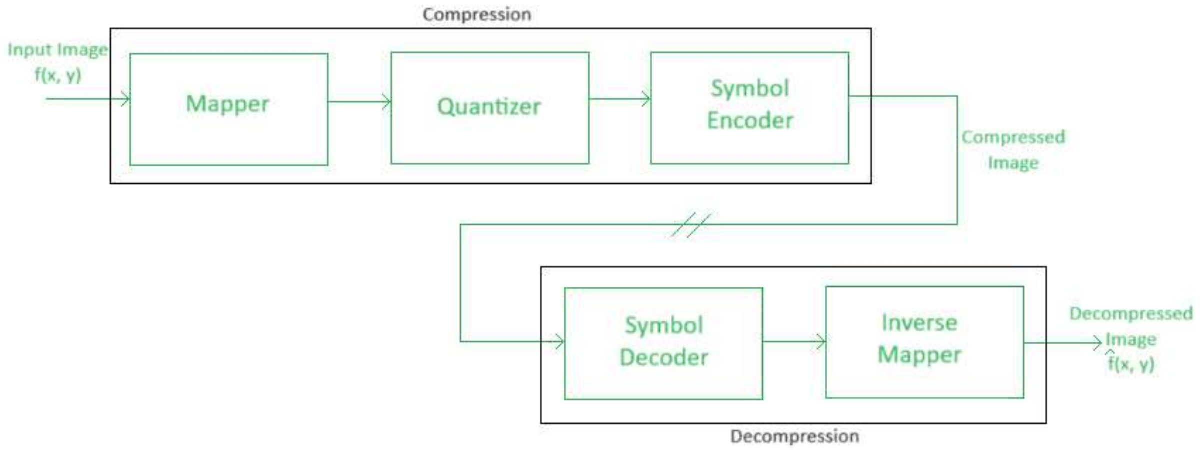


Image Compression Block Diagram

To get back the original image, we perform decompression going through the stage of symbol decoder and inverse mapper. Compression may be lossy or lossless.

7. Morphological Processing

This stage deals with tools which are used for extracting the components of the image, which is useful in the representation and description of shape.

we try to understand the structure of the image. We find the image components present in digital images. It is useful in representing and describing the images' shape and structure. We find the boundary, hole, connected components, convex hull, thinning, thickening, skeletons, etc. It is the fundamental step for the upcoming stages.

8. Segmentation

In this stage, an image is a partitioned into its objects. Segmentation is the most difficult tasks in DIP. It is a process which takes a lot of time for the successful solution of imaging problems which requires objects to identify individually. Segmentation is based on extraction information from images on the basis of two properties - similarity and discontinuity. For example, a sudden change in intensity value represents an edge. Detection of isolation points, line detection, edge detection are some of the tasks associated with segmentation. Segmentation can be done by various methods like thresholding, clustering, superpixels, graph cuts, region growing, region splitting and merging, morphological watersheds.

9. Representation and Description

Representation and description follow the output of the segmentation stage. The output is a raw pixel data which has all points of the region itself. To transform the raw data, representation is the only solution. Whereas description is used for extracting information's to differentiate one class of objects from another.

10. Object recognition

In this stage, the label is assigned to the object, which is based on descriptors.

11. Knowledge Base

Knowledge is the last stage in DIP. In this stage, important information of the image is located, which limits the searching processes. The knowledge base is very complex when the image database has a high-resolution satellite.

Applications

1. In medical diagnosis, Gamma ray imaging, X-ray imaging, ultrasound imaging, MRI imaging is used to know about the internal organs and bones of our body.

2. In satellite imaging and astronomy, infrared imaging is used.

3. In forensics, for biometrics such as thumbprints and retina scan, digital image processing is used.

4. We can find defects in manufactured packaged goods using microwave imaging.

5. We can find information about circuit boards and microprocessors.

6. Using image restoration, we can identify the car number plates of moving cars from CCTV for police investigations.

7. Beautify filters are used in social media platforms which use image enhancement.

Advantages of Digital Image Processing:

1. Improved image quality: Digital image processing algorithms can improve the visual quality of images, making them clearer, sharper, and more informative.

2. Automated image-based tasks: Digital image processing can automate many image-based tasks, such as object recognition, pattern detection, and measurement.

3. Increased efficiency: Digital image processing algorithms can process images much faster than humans, making it possible to analyze large amounts of data in a short amount of time.

4. Increased accuracy: Digital image processing algorithms can provide more accurate results than humans, especially for tasks that require precise measurements or quantitative analysis.

Disadvantages of Digital Image Processing:

1. High computational cost: Some digital image processing algorithms are computationally intensive and require significant computational resources.

2. Limited interpretability: Some digital image processing algorithms may produce results that are difficult for humans to interpret, especially for complex or sophisticated algorithms.

3. Dependence on quality of input: The quality of the output of digital image processing algorithms is highly dependent on the quality of the input images. Poor quality input images can result in poor quality output.

4. Limitations of algorithms: Digital image processing algorithms have limitations, such as the difficulty of recognizing objects in cluttered or poorly lit scenes, or the inability to recognize objects with significant deformations or occlusions.

5. Dependence on good training data: The performance of many digital image processing algorithms is dependent on the quality of the training data used to develop the algorithms.

Image acquisition-

In the simplest terms, image acquisition is the process of capturing visual information from the real world and converting it into a digital image that computers can process. Think of it as snapping a photo with your smartphone—the moment you hit the shutter button, you’re acquiring an image. Whether it’s a medical scan, a satellite photo, or a selfie, the fundamental goal remains the same: to translate physical scenes into digital data that can be analysed, edited, or enhanced.

However, image acquisition isn't just about taking pictures. It involves a variety of devices and technologies, from digital cameras and scanners to more complex systems like X-ray machines and LiDAR sensors. Each tool uses different methods to capture and convert light into pixelated data.

For instance, a digital camera uses a sensor to detect light and store it as digital information. At the same time, a scanner might utilize a different approach to capture highly detailed images of documents. The versatility and application scope of image acquisition make it a cornerstone in fields ranging from healthcare to remote sensing, paving the way for advancements in artificial intelligence and machine learning.

Why Is Image Acquisition Important?

Think of image acquisition as the crucial first step in building a high-quality digital image pipeline. Effective image processing and analysis hinge on the initial image acquisition. Here are the key reasons why this process is so pivotal:

- **Data Quality**: Ensuring high-quality image acquisition provides a solid foundation by capturing accurate and detailed raw data, essential for reliable processing.
- **Application Accuracy**: In areas such as facial recognition, medical imaging, and autonomous vehicles, precise image acquisition directly influences the accuracy and dependability of the application.
- **Processing Efficiency**: High-quality images enable algorithms to function more efficiently, minimizing the need for extensive preprocessing and error correction.
- **Versatility**: Employing diverse acquisition methods allows for a broad range of applications, from standard photography to specialized areas like satellite imaging and microscopy.
- **Foundation for Innovation**: Advanced technologies, including machine learning and artificial intelligence, rely heavily on high-quality visual data to improve and evolve, making robust image acquisition indispensable for future advancements.

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