Digital Image Processing

- **Define Image:** Image may be defined as two dimensional light intensity function f(x, y) where x and y denote spatial co-ordinate and the amplitude or value of f at any point(x, y) is called intensity or gray scale or brightness of the image at that point.

  NOTE:

  a) An image is also a two-dimensional array or a matrix pixel (picture elements) specifically arranged in rows and columns.

  b) **Image As a Matrix** –

  a. A digital gray scale image is presented in the computer by pixels matrix. Each pixel of such an image is presented by one matrix element – an integer from the set. The numeric values in pixel presentation are uniformly changed from zero (black pixels) to 255 (white pixels).

  b. When it comes to a binary or Boolean image that comprises of only two colors, i.e., black and white, the matrix represents the color black as 0 and the color white as 1.

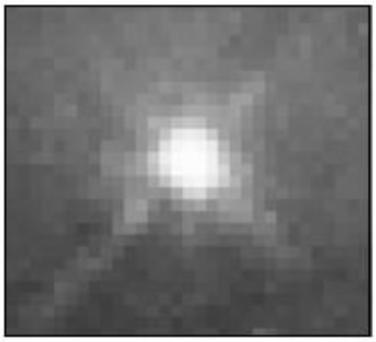


Figure 1: An image — an array or a matrix of pixels arranged in columns and rows.

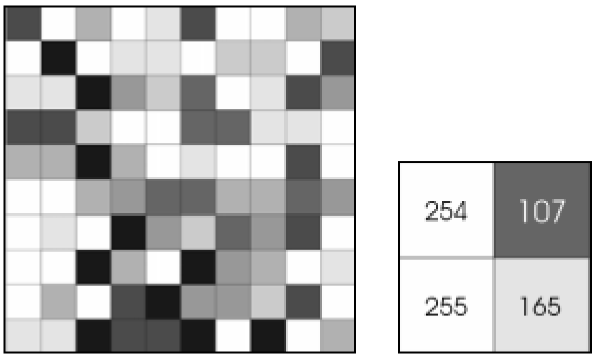


Figure 2: Each pixel has a value from 0 (black) to 255 (white). The possible range of the pixel values depend on the colour depth of the image, here 8 bit = 256 tones or greyscales.

- **Characteristics of Image:** An image can be characterized on following parameters -
  - Image can be real or virtual.
  - Image can or cannot have left-right reversal.
  - Image can be upright or inverted.
  - Image can be magnified, diminished or of same size as the object.

- **Types of Images:**
    - **Binary Image –** The binary image contains only two pixel elements 0 & 1. ***Here, 0 refers to black and 1 refers to white. This is also known as Monochrome***.
    - **Black and White Image (8 bit color format) –** The image contains black and white color. ***8 bit color Format – It has 256 different shades of colors and known as Gray scale Image. In this format, 0 stands for Black, and 255 stands for white, and 127 stands for Gray.***
    - **16 Bit Color Format –** It has different colors and is known as a ***High Color Format***. The distribution of Color is not the same as a Gray scale image.

- **Origin of Images:** Digital image processing has a fascinating history that dates back to the early 20th century.
    - **Early Beginnings:** The concept of digital image processing began with the Bartlane cable picture transmission system in the early 1920s. This system allowed pictures to be sent between London and New York in a matter of hours instead of weeks.
    - **1960s and 1970s:** The field truly took off in the 1960s and 1970s with the development of computers and advancements in mathematics. Researchers at institutions like Bell Laboratories, the Jet Propulsion Laboratory, and MIT began applying digital image processing techniques to satellite imagery, medical imaging, and character recognition.
    - **Medical Imaging:** One of the first major applications was in medical imaging, particularly with the invention of computerized axial tomography (CAT) or CT scans in the early 1970s.
    - **Space Exploration:** The American Jet Propulsion Laboratory (JPL) used digital image processing techniques on lunar photos sent back by the Space Detector Ranger 7 in 1964. This helped create detailed maps of the Moon's surface, which was crucial for the Apollo missions.
    - **Advancements in Technology:** As computers became more powerful and affordable in the 1970s, digital image processing became more widespread. This led to real-time image processing for applications like television standards conversion and various industrial uses.

Digital image processing has since evolved significantly, with applications in fields ranging from medical diagnostics to autonomous vehicles and beyond.

- **Applications of Image Processing:** Applications of Image Processing Digital image processing has a wide range of applications across various fields.
    - **Medical Imaging:** Image processing techniques are crucial in medical diagnostics. They enhance and analyze images from X-rays, MRI, CT scans, and ultrasound to detect diseases, plan treatments, and monitor progress.
    - **Remote Sensing:** Satellites use image processing to monitor and analyze the Earth's surface. This is vital for environmental monitoring, weather forecasting, agriculture, and urban planning.
    - **Biometrics:** Facial recognition, fingerprint recognition, and iris recognition systems use image processing for security and identification purposes.
    - **Automotive Industry:** Image processing plays a key role in developing autonomous vehicles. It helps in object detection, lane detection, and navigation.

- **Quality Control:** In manufacturing, image processing is used for inspecting products, detecting defects, and ensuring quality.

- **Entertainment:** Special effects in movies, video games, and augmented reality (AR) applications heavily rely on image processing techniques.

- **Robotics:** Image processing enables robots to understand and interact with their environment, making them more efficient in tasks like sorting, assembling, and navigation.

- **Optical Character Recognition (OCR):** OCR technology converts different types of documents, such as scanned paper documents, PDFs, or images captured by a digital camera, into editable and searchable data.

- **Forensics:** Image processing is used to enhance and analyze crime scene photos, fingerprints, and video footage to aid in criminal investigations.

- **Healthcare:** Besides diagnostics, image processing helps in telemedicine, where doctors can consult with patients remotely using high-quality images and videos.

■ **Components of Image Processing:** Digital image processing encompasses several fundamental components that work together to process and analyze images.

- **Image Sensors:** Devices like digital cameras, scanners, or specialized sensors that capture images. These sensors convert light into electronic signals that can be processed by computers.

- **Image Processing Software:** Programs and algorithms that perform various image processing tasks. These include software for enhancing, restoring, and analyzing images. Examples include Photoshop for general editing and specialized medical imaging software for diagnostic purposes.

- **Computer Hardware:** Powerful processors, graphics cards, and memory are essential for handling the computational demands of image processing. High-performance hardware can significantly speed up processing times.

- **Mathematical Algorithms:** The backbone of image processing, these algorithms perform tasks like filtering, edge detection, segmentation, and transformation. They are designed to manipulate pixel values to achieve the desired effect.

- **Storage Devices:** Images and processed data need to be stored efficiently. This involves the use of various storage media, including hard drives, solid-state drives, and cloud storage.

- **Display Devices:** Monitors, screens, and projectors are used to visualize processed images. High-resolution and color-accurate displays are crucial for applications like medical imaging and graphic design.

- **User Interfaces:** Software interfaces that allow users to interact with image processing tools. These interfaces are designed to be user-friendly and provide easy access to various functionalities.

- **Network Infrastructure:** For applications involving remote sensing, telemedicine, or cloud-based processing, robust network infrastructure is essential to transmit images and data between different locations.

- **Data Acquisition Hardware:** Specialized equipment used to capture image data from various sources, such as microscopes, telescopes, or medical imaging devices. This hardware ensures high-quality data for processing.

- **Machine Learning Models:** Increasingly, image processing involves the use of machine learning and deep learning models. These models are trained to perform tasks like object detection, image classification, and pattern recognition.

These components work together to create powerful image processing systems capable of handling a wide variety of applications.

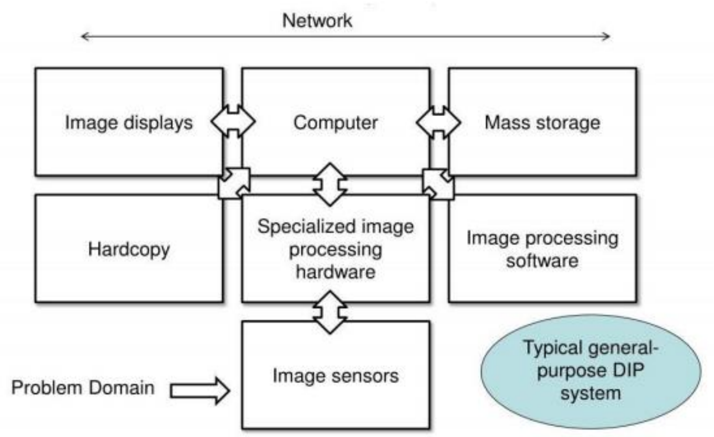


Fig: Components of Image processing System

■ **Image Quantization:** Image quantization is the process of reducing the number of colors in an image while preserving its essential visual features.
It involves:
- **Color space reduction:** Decreasing the number of bits used to represent each pixel's color information.
- **Color palette selection:** Choosing a limited set of colors (color map) to represent the image.
- **Color assignment:** Mapping the original colors to the selected colors in the palette.

Quantization techniques:
- **Uniform quantization:** Dividing the color range into equal intervals.
- **Non-uniform quantization:** Dividing the color range into unequal intervals based on the image's color distribution.
- **Dithering:** Adding noise to the image to create the illusion of more colors.

■ **Quantization is used to:**
- Reduce image file size
- Decrease memory usage
- Improve image transmission efficiency
- Enhance image display on devices with limited color capabilities

However, quantization can lead to:
- Color loss and distortion
- Posterization (banding effects)
- Loss of subtle color gradations

NOTE: Striking a balance between image quality and file size is crucial when applying image quantization.

- **Briefly Explain the Elements of Visual Perception -**
    - **Line:** A continuous mark made on a surface by a moving point.
    - **Shape:** A self-contained area with height, width, and depth.
    - **Form:** A three-dimensional volume created by lines, shapes, and textures.
    - **Texture:** The surface quality or "feel" of an object.
    - **Color:** The property of an object that is perceived by the eye as a result of the way it reflects or emits light.
    - **Size:** The relative magnitude of an object.
    - **Direction:** The orientation of an object or line in space.
    - **Position:** The location of an object in relation to others.

    - **Proximity:** The closeness or distance between objects.
    - **Depth:** The perception of three-dimensional space, creating a sense of distance or layers.

- **Write brief note on different techniques of image sensing and acquisition?**
    - **CCD (Charge-Coupled Device) Imaging:** Captures images by converting light into electrical charges, which are then transferred and processed.

    - **CMOS (Complementary Metal-Oxide-Semiconductor) Imaging:** Uses a semiconductor chip to capture images, offering low power consumption and high speed.

    - **Infrared Imaging:** Detects temperature differences, capturing images in low-light environments or for thermal analysis.

    - **Multispectral Imaging:** Collects data from multiple spectral bands, revealing information not visible to the human eye.

    - **Hyper spectral Imaging:** Captures detailed spectral data, allowing for material identification and analysis.

    - **Stereo Vision:** Uses two or more cameras to capture the same scene from different angles, enabling depth perception and 3D reconstruction.

    - **Structured Light Imaging:** Projects patterns onto a scene, measuring distortions to calculate depth and surface information.

    - **LIDAR (Light Detection and Ranging):** Emits laser light, measuring reflections to create high-resolution 3D point clouds.

    - **Radar Imaging:** Uses radio waves to detect and image objects, often used in surveillance and navigation.

    - **Computed Tomography (CT) Imaging:** Reconstructs images from X-ray or other data, visualizing internal structures.

These techniques enable various applications, including machine vision, remote sensing, medical imaging, and more.

- **Write a short note on Electro Magnetic Spectrum and its subdivisions?**

The Electromagnetic (EM) Spectrum is the range of all possible frequencies of electromagnetic radiation, including-

- **Radio Waves:** Longest wavelength, lowest frequency (e.g., AM/FM radio, TV broadcasting)
- **Microwaves:** Medium wavelength, medium frequency (e.g., heating, wireless communication)
- **Infrared (IR) Radiation:** Shorter wavelength, higher frequency (e.g., heat, thermal imaging)
- **Visible Light:** Narrow range of wavelengths, perceived by the human eye
- **Ultraviolet (UV) Radiation:** Short wavelength, high frequency (e.g., disinfection, curing inks)
- **X-Rays:** High-energy, short wavelength (e.g., medical imaging, security screening)
- **Gamma Rays:** Highest energy, shortest wavelength (e.g., medical treatment, scientific research)

These subdivisions represent the entire EM Spectrum, with each range having unique properties and applications.

- **Here are some common image sampling algorithms:**
  - **Nearest-Neighbor (NN) Interpolation:**
    - Replaces pixels with the nearest neighbor's value.
    - Fast but may produce aliasing artifacts.
  - **Bilinear Interpolation:**
    - Averages neighboring pixels to create new ones.
    - Better than NN, but may still produce aliasing.
  - **Bicubic Interpolation:**
    - Uses a weighted average of neighboring pixels.
    - Higher quality than bilinear, but slower.
  - **Lanczos Interpolation:**
    - Uses a Lanczos filter to resample the image.
    - High-quality, but slower than bicubic.
  - **Box Sampling:**
    - Uses a box filter to average neighboring pixels.
    - Fast, but may produce aliasing artifacts.
  - **Gaussian Sampling:**
    - Uses a Gaussian filter to blur and sample the image.
    - Reduces aliasing, but may blur details.
  - **Sinc Interpolation:**
    - Uses a sinc filter to resample the image.
    - High-quality, but slower than Lanczos.
  - **Mitchell-Netravali Interpolation:**
    - Uses a weighted average of neighboring pixels.
    - High-quality, but slower than bicubic.
  - **Catmull-Rom Interpolation:**
    - Uses a weighted average of neighboring pixels.
    - High-quality, but slower than bicubic.

- **Linear and Nonlinear Operations between pixels –**
  Linear and nonlinear operations are fundamental concepts in image processing, used to transform and analyze images.

  Linear Operations - Linear operations involve a weighted sum of neighboring pixels, preserving the linear relationship between pixels.
  Examples include -
  - **Convolution:** A weighted sum of neighboring pixels, using a kernel or filter.
  - **Averaging:** Replacing a pixel value with the average of neighboring pixels.
  - **Blurring:** Averaging neighboring pixels to reduce image sharpness.

  Nonlinear Operations - Nonlinear operations involve a nonlinear transformation of pixel values, enhancing or detecting specific image features.
  Examples include –

  - **Thresholding:** Setting pixel values to a specific value based on a threshold.
  - **Edge detection:** Identifying pixels with significant intensity changes.
  - **Median filtering:** Replacing a pixel value with the median of neighboring pixels.

  Key Differences –
  a) **Linearity:** Linear operations preserve the linear relationship between pixels, while nonlinear operations do not.

  b) **Computational complexity:** Linear operations are generally faster and more efficient than nonlinear operations.

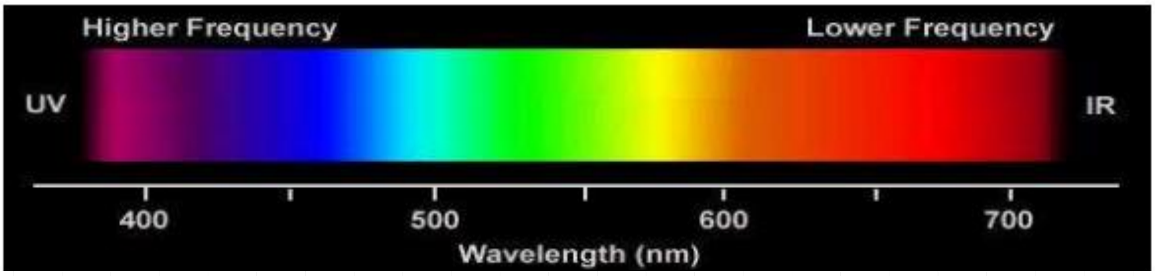
  c) **Image characteristics:** Linear operations tend to preserve image smoothness, while nonlinear operations can enhance or detect specific image features.

  Applications - Linear and nonlinear operations are used in various image processing applications, including -
  - **Image filtering (e.g., blurring, sharpening)**
  - **Image enhancement (e.g., contrast adjustment, noise reduction)**
  - **Image analysis (e.g., edge detection, feature extraction)**
  - **Image segmentation (e.g., thresholding, clustering)**

- **What is Light?**
  a) Light exhibits some properties that make it appear to consist of particles; at other times, it behaves like a wave.

  b) Light is electromagnetic energy that radiates from a source of energy (or a source of light) in the form of waves

  c) Visible light is in the 400 nm – 700 nm range of electromagnetic spectrum



- **INTENSITY OF LIGHT -**
  - ***The strength of the radiation from a light source is measured using the unit called the candela, or candle power.*** The total energy from the light source, including heat and all electromagnetic radiation, is called radiance and is usually expressed in watts.

  - ***Luminance is a measure of the light strength that is actually perceived by the human eye. Radiance is a measure of the total output of the source***; luminance measures just the portion that is perceived.

  - ***Brightness is a subjective, psychological measure of perceived intensity***. Brightness is practically impossible to measure objectively. It is relative. For example, a burning candle in a darkened room will appear bright to the viewer; it will not appear bright in full sunshine.

  - The strength of light diminishes in inverse square proportion to its distance from its source. This effect accounts for the need for high intensity projectors for showing multimedia productions on a screen to an audience. Human light perception is sensitive but not linear.

- **Define Image Sampling.**

  The process of converting continuous spatial co-ordinates into its digitized form is called as sampling. Image sampling refers to the process of converting a continuous-tone image (analog) into a digital form. This involves measuring the intensity values of the image at discrete points, known as pixels.

- **Key Concepts in Image Sampling -**

  a) Sampling Rate:

  - The sampling rate, or spatial resolution, refers to the number of samples (pixels) taken per unit area of the image.

  - Higher sampling rates result in higher resolution images with more detail, while lower sampling rates can lead to loss of detail and image quality.

  b) Nyquist Theorem:

  - This theorem states that to accurately sample a continuous signal without losing information, the sampling rate must be at least twice the highest frequency present in the signal.

  - In image processing, this translates to having a sufficiently high resolution to capture all the details in the image.

  c) Quantization:

  - Quantization is the process of mapping the continuous range of intensity values in the image to discrete levels.

  - This step follows sampling and involves assigning each pixel a specific value from a finite set of levels, often based on the bit depth (e.g., 8-bit, 16-bit).

- **Steps in Image Sampling -**

  a) Scanning:

  - An image sensor scans the continuous-tone image and measures the intensity of light at each discrete point.
  - The output is a grid of pixels, each with an intensity value.

b) Digitization:

- The intensity values measured during scanning are digitized by converting them to a finite number of levels.
- This process results in a digital image composed of pixels with discrete intensity values.

c) Reconstruction:

- The digital image can be reconstructed or displayed by mapping the discrete pixel values back to a visual representation.
- Techniques like interpolation can be used to improve the appearance of the reconstructed image.