الجامعة المستنصريـــــــــــــة / كليـــــــــــة العلوم

قســـــم الفيزيـــــــــاء

Mustansiriyah University

College of Science

Physics Department

Digital Image Processing

2020-2021

Lecture (1) for PhD

Digital Image Formation

Edited by: Prof. Dr. Ali .A. Al-Zuky

• Digital Image

Early 1920s: One of the first applications of digital imaging was in the news-paper industry

- Images were transferred by submarine cable between London and New York
- Pictures were coded for cable transfer and reconstructed at the receiving end on a telegraph printer

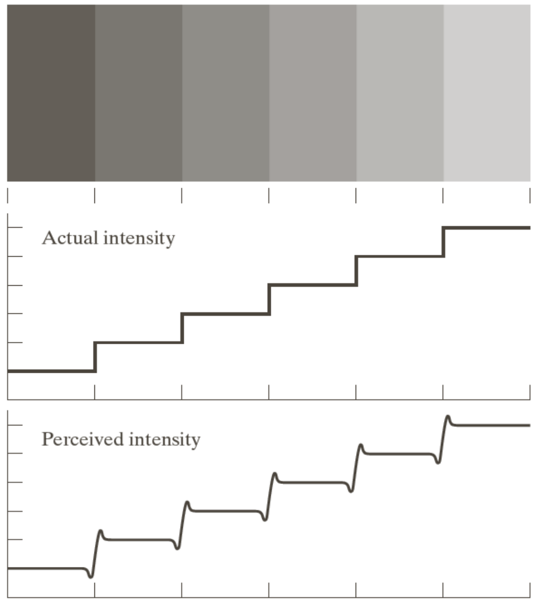
Early digital image

1980s - Today: The use of digital image processing techniques has exploded and they are now used for all kinds of tasks in all kinds of areas (Image enhancement/restoration, Artistic effects, Medical visualisation, Industrial inspection, Law enforcement, and Human computer interfaces)

2.1 Elements of Visual Perception

Although the field of digital image processing is built on a foundation of mathematical and probabilistic formulations, human intuition and analysis play a central role in the choice of one technique versus another, and this choice often is made based on subjective, visual judgments. Hence, developing a basic understanding of human visual perception as a first step in our journey through this book is appropriate. Given the complexity and breadth of this topic, we can only aspire to cover the most rudimentary aspects of human vision.

In particular, our interest is in the mechanics and parameters related to how images are formed and perceived by humans. We are interested in learning the physical limitations of human vision in terms of factors that also are used in our work with digital images. Thus, factors such as how human and electronic imaging devices compare in terms of resolution and ability to adapt to changes in illumination are not only interesting, they also are important from a practical point of view.



a
b
c

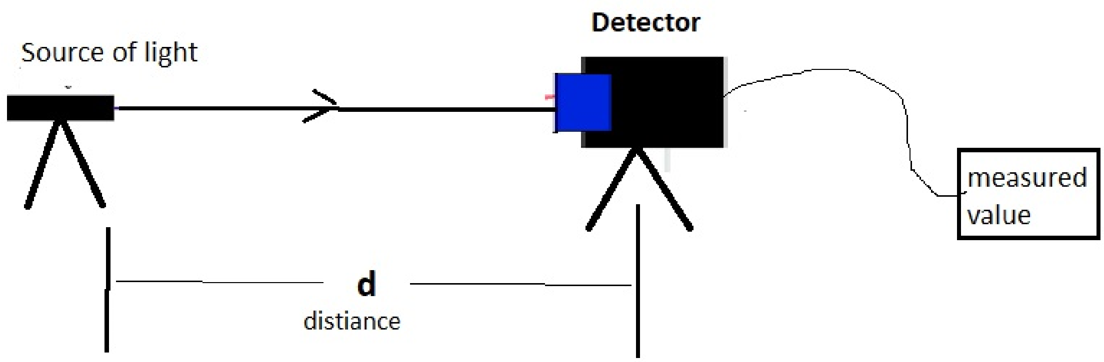
Illustration of the Mach band effect. Perceived intensity is not a simple function of actual intensity.

a b c

Examples of simultaneous contrast. All the inner squares have the same intensity, but they appear progressively darker as the background becomes lighter.

Conventional Physical Measurement

Physics experiments are usually performed by reading and recording calculations of the finite physical parameters. For example, we can measure the intensity of light as a function of distance. Where the light intensity is measured as a function of the distance between the light source and the detector (i.e. represented by the 1D signal) see the figure below. Therefore, limited data can be recorded which can be easily manipulated and can be drawn on graph paper easily and directly. This occurs in most traditional physics experiments and research.

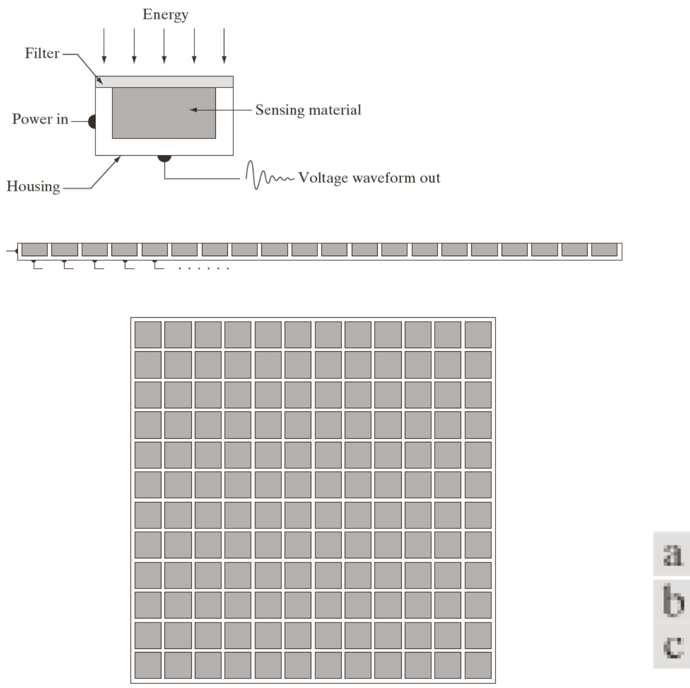


The process of recording or capturing photos (2D signal) is a process usually requires a light source within a specific spectral range that is used to illuminate a scene and then take a picture of this scene using the camera, where the camera represent an optical system. That used to recorded or captured images, according to the concepts of optics. Here the image is formed on a light sensitive surface 2D plane that records light intensity coming from the scene objects. This plane surface is a light intensity detector. It consists of two light intensity detectors types:

- The first type is the chemical photosensitive films that were popular before the advent of digital cameras in recent decades.
- The second type is two-dimensional (2D) electronic sensors that record the optical density and create a digital matrix representing the detected optical density, which can be saved or sent over various digital communication networks in the form of two-dimensional arrays and can be displayed as a matrix image on the screens of special devices such as mobile phones, digital cameras, computers and others.

Digital images usually contain huge numbers of data that have been measured and recorded for a specific physical state. The vast amount of this data cannot be handled easily by hand and the information cannot be extracted easily and cannot be drawn manually. Therefore, the processing and extracting information from it requires using the computer and adopted the mathematical physics. Also, it is not possible to dispense with mathematical statistics to analysis image information,

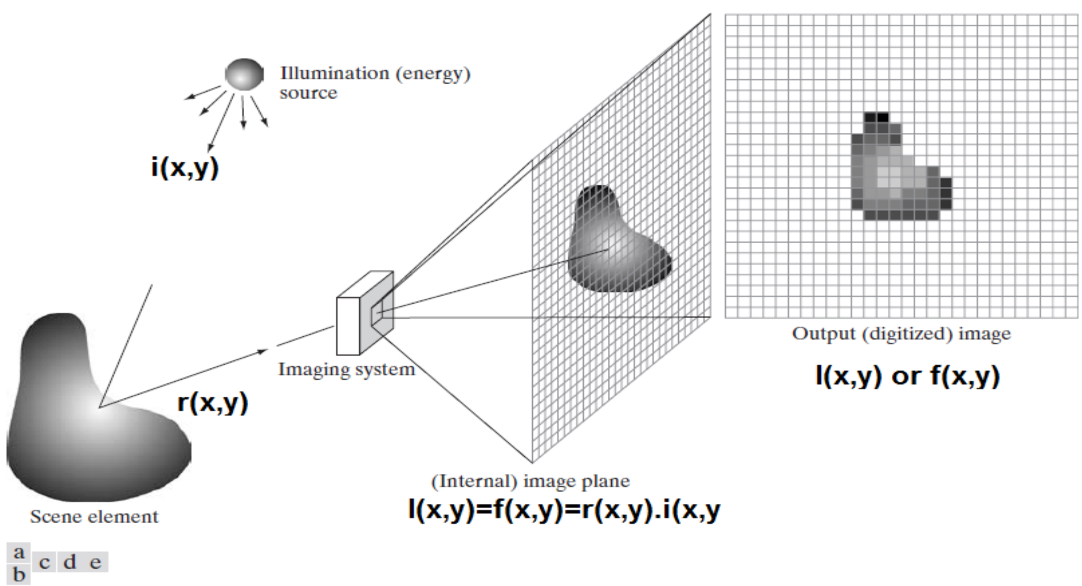
The following figure shows that the 2D image formation process for a 3D scene view and the process of converting it to digital image *f(x,y) or I(x,y)*.



a) Single imaging sensor.
b) Line Sensor.
c) Array sensor.

A Simple Image Formation Model

As previously introduced, we denote images by two-dimensional functions of the form *f(x,y)*. The value or amplitude of *f* at spatial coordinates *(x,y)* is a positive scalar quantity whose physical meaning is determined by the source of the image. When an image is generated from a physical process, its intensity values are proportional to energy radiated by a physical source (e.g., electromagnetic waves).



Figure(1): An example of the digital image acquisition process. (a) Energy ("illumination") source. (b) An element of a scene. (c) Imaging system. (d) Projection of the scene onto the image plane. (e) Digitized image.

The *f(x,y) or I(x,y)* values must finite; that is,

$$0 < f(x, y) < \infty \quad \text{-------}(1)$$

The function *f(x,y)* may be characterized by two components: (1) the amount of source illumination incident on the scene being viewed, and (2) the amount of illumination reflected by the objects in the scene. Appropriately, these are called the *illumination* and *reflectance* components and are denoted by *i(x,y)* and *r(x,y)*, respectively. The two functions combine as a product to form *f(x,y)*:

$$f(x,y) = i(x,y)r(x,y) \;.......(2)$$

where:

$$0 < i(x, y) < \infty \quad .....(3)$$

And

$$0 < r(x, y) < 1 \quad ......(4)$$

Last equation indicates that reflectance is bounded by 0 (total absorption) and 1 (total reflectance). The nature of *i(x,y)* is determined by the illumination source, and *r(x,y)* is determined by the characteristics of the imaged objects.

It is noted that these expressions also are applicable to images formed via transmission of the illumination through a medium, such as a chest X-ray. Where used the transmittance *t(x,y)* instead of using *r(x,y)*:

$$f(x,y)=i(x,y)t(x,y).....(5)$$

While image of a luminous object such as stars can be represented by mathematical form:

$$f(x,y)=i(x,y)......(6)$$

Real illumination in real scene represent function of i(x,y,z,λ), and the object points reflectivity r(x,y,z,λ) in 3D space world converted into 2D space in image world f(x,y) or I(x,y). The third dimension z will be reduced to the image space as its effect is transformed into an effect on the recorded intensity of the image element. As for the wavelength (λ) or the spectral beam used to illuminate the scene, it has been neglected in the mathematical formula of the resulting image because each spectral beam will have its own sensor to record this spectral image.

Exmple1: Some typical values of illumination and reflectance.

The values given in Eqs.(2.and 3) are theoretical bounds. The following *average* numerical figures illustrate some typical ranges of *i(x,y)* for visible light. On a clear day, the sun may produce in excess of 90,000 lm/m^2 of illumination on the surface of the Earth. This figure decreases to less than 10000 lm/m^2 on a cloudy day. On a clear evening, a full moon yields about of illumination. The typical illumination level in a commercial office is about Similarly, the following are typical values of :0.01lm/m^2 for black velvet, 0.65 for stainless steel, 0.80 for flat-white wall paint, 0.90 for silver-plated metal, and 0.93 for snow.

Let the intensity (gray level) of a monochrome image at any coordinates be (x0,y0)denoted by**:**

$$\ell = f(x_0, y_0) \quad ....(7)$$

From Eqs. (2) through (4), it is evident that ℓ lies in the range*:*

$$L_{\min} \leq \ell \leq L_{\max} \quad ......(8)$$

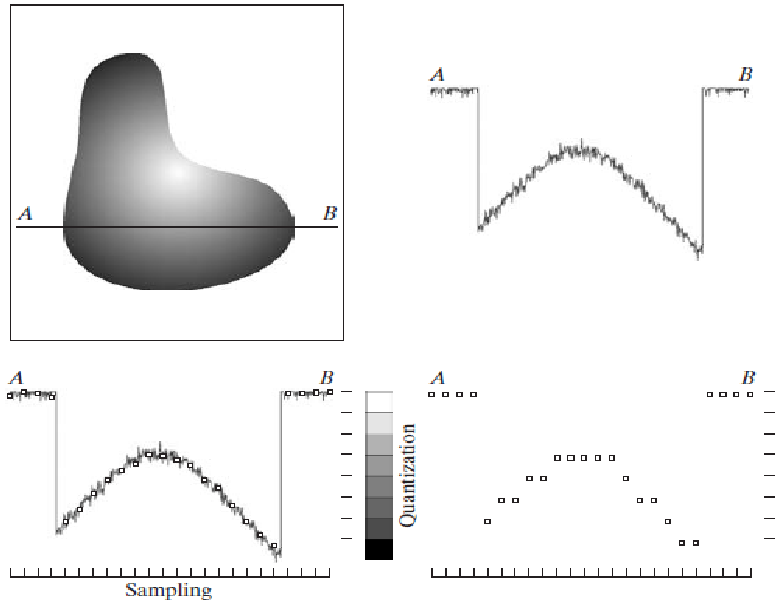
In theory, the only requirement on $L_{\min}$ is that it be positive, and on $L_{\max}$ that it be finite. In practice, $L_{\min} = i_{\min} r_{\min}$ and $L_{\max} = i_{\max} r_{\max}$. Using the preceding average office illumination and range of reflectance values as guidelines, we may expect $L_{\min} \approx 10$ and $L_{\max} \approx 1000$ and to be typical limits for indoor values in the absence of additional illumination. The interval is called the *gray* (or *intensity*) *scale*. Common practice is to shift this interval numerically to the interval $[0, L-1]$, where $\ell = 0$ is considered black and $\ell = L-1$ is considered white on the gray scale. All intermediate values are shades of gray varying from black to white.

Image Sampling and Quantization

From the discussion in the preceding section, we see that there are numerous ways to acquire images, but our objective in all is the same: to generate digital images from sensed data. The output of most sensors is a continuous voltage waveform whose amplitude and spatial behavior are related to the physical phenomenon being sensed. To create a digital image, we need to convert the continuous sensed data into digital form. This involves two processes: *sampling* and *quantization*

Basic Concepts in Sampling and Quantization

The basic idea behind sampling and quantization is illustrated in figure below below. Figure (2:a) shows a continuous image *f* that we want to convert to digital form. An image may be continuous with respect to the *x*- and *y*-coordinates, and also in amplitude. To convert it to digital form, we have to sample the

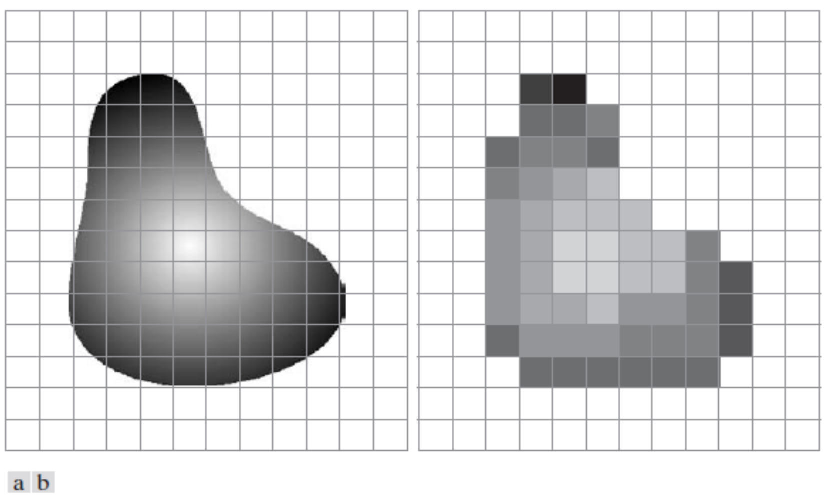


a b
c d **Figure(2)**: Generating a digital image. (a) Continuous image. (b) A scan line from *A* to *B* in the continuous image, used to illustrate the concepts of sampling and quantization. (c) Sampling and quantization. (d) Digital scan line.

function in both coordinates and in amplitude. Digitizing the coordinate values is called *sampling*. Digitizing the amplitude values is called *quantization*. The one dimensional function in figure (2b) is a plot of amplitude (intensity level) values of the continuous image along the line segment *AB* in figure (2a). The random variations are due to image noise. To sample this function, we take equally spaced samples along line *AB*, as shown in figure (2c).The spatial location of each sample is indicated by a vertical tick mark in the bottom part of the figure. The samples are shown as small white squares superimposed on the function. The set of these discrete locations gives the sampled function. However, the values of the samples still span (vertically) a continuous range of intensity values. In order to form a digital function, the intensity values also must be converted (*quantized*) into discrete quantities. The right side of figure (2c) shows the intensity scale divided into eight discrete intervals, ranging from black to white. The vertical tick marks indicate the specific value assigned to each of the eight intensity intervals. The continuous intensity levels are quantized by assigning one of the eight values to each sample. The assignment is made depending on the vertical proximity of a sample to a vertical tick mark. The digital samples resulting from both sampling and quantization are shown in figure (2d). Starting at the top of the image and carrying out this procedure line by line produces a two-dimensional digital image. It is implied in figure (2) that, in addition to the number of discrete levels used; the accuracy achieved in quantization is highly dependent on the noise content of the sampled signal. Sampling in the manner just described assumes that we have a continuous image in both coordinate directions as well as in amplitude.

In practice, the method of sampling is determined by the sensor arrangement used to generate the image. When an image is generated by a single sensing element combined with mechanical motion, the output of the sensor is quantized in the manner described above. However, spatial sampling is accomplished by selecting the number of individual mechanical increments at which we activate the sensor to collect data. Mechanical motion can be made very exact so, in principle; there is almost no limit as to how fine we can sample an image using this approach. In practice, limits on sampling accuracy are determined by other factors, such as the quality of the optical components of the system. When a sensing strip is used for image acquisition, the number of sensors in the strip establishes the sampling limitations in one image direction. Mechanical motion in the other direction can be controlled more accurately, but it makes little sense to try to achieve sampling density in one direction that exceeds the sampling limits established by the number of sensors in the other. Quantization of the sensor outputs completes the process of generating a digital image. When a sensing array is used for image acquisition, there is no motion and the number of sensors in the array establishes the limits of sampling in both directions.

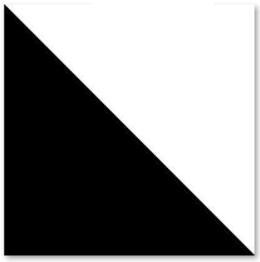
Quantization of the sensor outputs is as before. figure (3) illustrates this concept. figure (3a) shows a continuous image projected onto the plane of an array sensor. Figure(3b) shows the image after sampling and quantization. Clearly, the quality of a digital image is determined to a large degree by the number of samples and discrete intensity levels used in sampling and quantization.



Figure(3) (a) Continuous image projected onto a sensor array. (b) Result of image sampling and quantization.

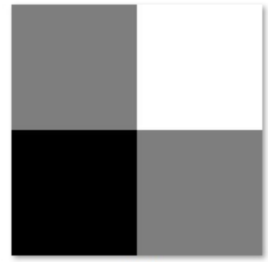
Image resolutions:

1. **Spatial resolution (pixel size);**
2. **Radiometric (pixel intensity) resolution.**
3. **Spectral resolutions (number of bands or colors).**
4. **Temporal resolution (number of image per unit time)**

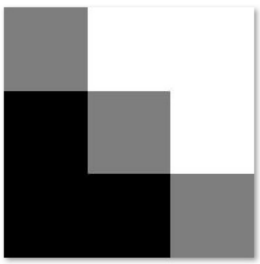


Original image

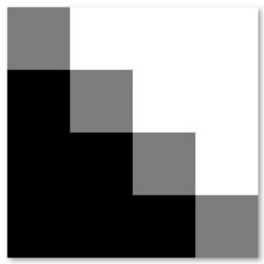
1 pixel image



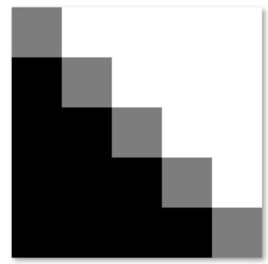
2*2 pixels image



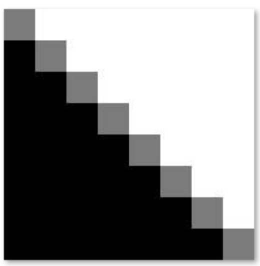
3*3 pixels image



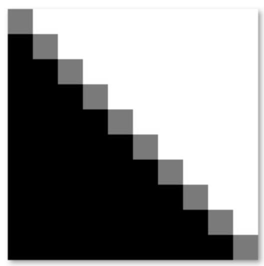
4*4 pixels image



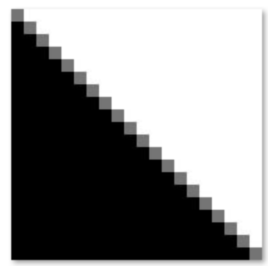
5*5 pixels image



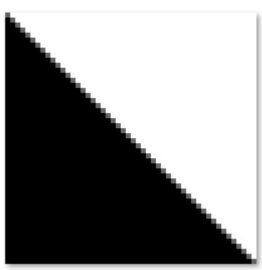
8*8 pixels image



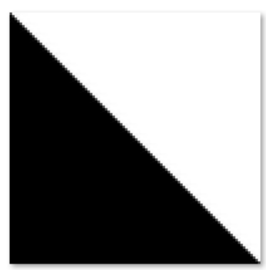
10*10 pixels image



20*20 pixels image



50*50 pixels image



100*100 pixels image

Image Spatial resolutions

256

128

64

32

16

8

4

2

Image Intensity (radiometric) resolutions

Form 256 levels to 2 levels

The most utilized digital images and videos:

1. Binary images presented by (1bpp).
2. Gray level images (256 gray levels) or presented by 8bpp.
3. True color images (RGB-color images) presented by number of colors (2^{24}) or presented by (24bpp).
4. Multispectral images TM images and MSS images.
5. Digital Video frames (sequence of color images in video clip), where the number of frames is always used higher than 30 frames per second(fps).

Reference:

Rafael C. Gonzalez& Richard E. Woods," Digital Image Processing" Third Edition, Pearson Prentice Hall, Pearson Education, Inc., ,2008.