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"Digital Imaging Concepts and Applications"

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INTRODUCTION

One of the most significant changes occurring in medical imaging is the transition from film and video based analog to digital images. While analog images are still required for human viewing there are significant advantages in having images in a digital form at other stages of the imaging process. The advantages come from the many functions which can only be performed, or performed better, with digitized images. Figure 1 illustrates a general comprehensive medical imaging system in which these various functions are identified. These functions will be introduced in this chapter and explored in much greater detail in later chapters.

A digital image is represented by discrete numerical values rather than directly by characteristics such as brightness, shades of gray, or colors as in analog images. A specific numerical value in a digitized image generally represents a level of one of the characteristics in a corresponding analog image. The conversion of an analog image to a digital form requires two distinct actions. The first is sampling which divides the analog image into small elements or samples which are known as pixels (picture elements). The second is quantization which associates a discrete numerical value with the analog characteristic in that specific pixel.

Imaging methods, such as human vision and x-ray imaging, which create images directly from the human body, produce analog images. In many applications these are then converted into a digital form and then later reconverted into

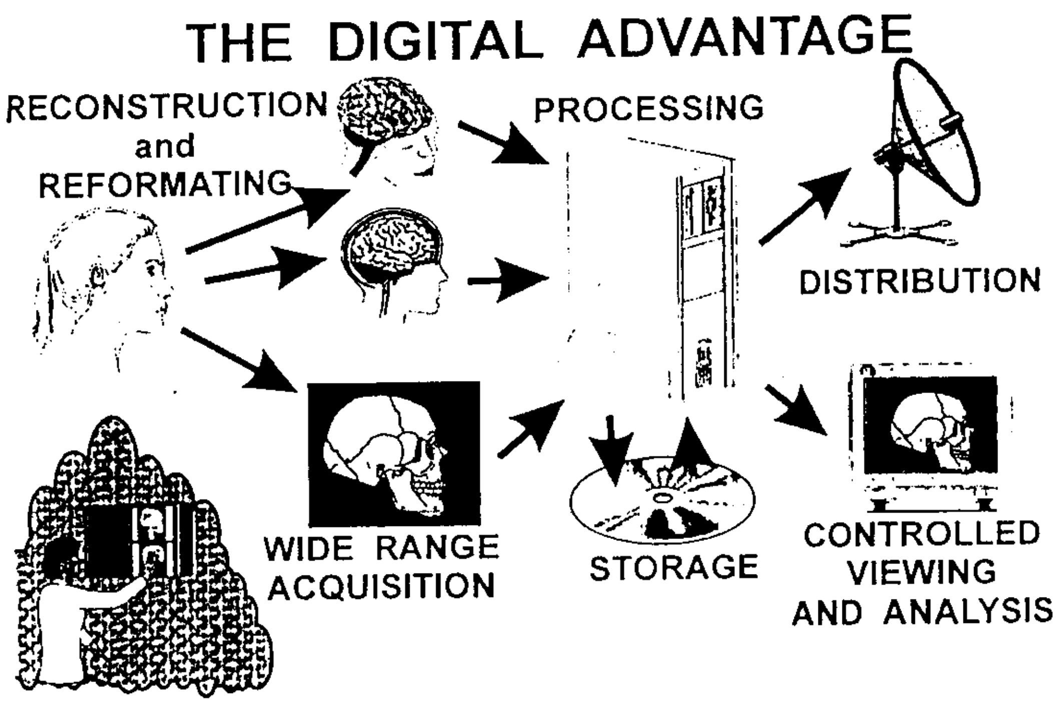

Figure 1. Functions which can be performed with digitized images that give a general advantage over images recorded on film.

an analog form for visual display as illustrated in Figure 1. Perhaps this raises the question as to why it is necessary or desirable to convert images into a digital form. Digital images have two very significant characteristics which contribute to many medical imaging applications. Because they are in a digital form they can be processed by digital computers. This makes many of the functions illustrated in Figure 1 possible. The second advantage is that each element is represented by a discrete numerical value which maintains its integrity throughout operations such as processing, transmission, storage, and retrieval. That is, a digital image maintains its fidelity and is not degraded in quality by these functions.

2. DIGITAL IMAGE STRUCTURE

A digital image is composed of a large number of individual discrete elements, pixels and bits. The general structure is illustrated in Figure 2.

A. Pixel Matrix

The image area is subdivided into a matrix of individual pixels. Each pixel has a numerical value which is related to an image characteristic such as a shade of gray or brightness. The physical size of an individual pixel is the ratio of the physical size of the image, that is the field of view (FOV), and the numerical matrix size. The numerical matrix size is the number of pixels along the length or width of the matrix. Pixel size is one of the predominant characteristics of a digital image and must be adjusted to meet the image quality requirements in various clinical applications. The significance of pixel size and these controlling factors will be considered later.

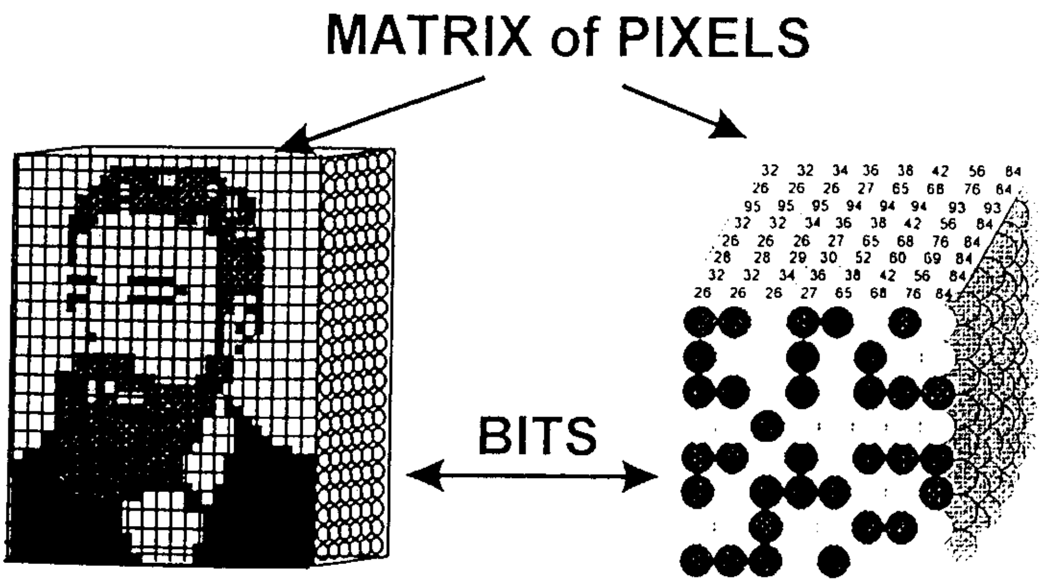

Figure 2. The basic structure of a digital image. The image area is a matrix of pixels each of which is represented by a cluster of bits.

B. Pixel Bit Depth

Each pixel in a digitized image is represented by a series of binary digits or bits. As the name "binary" implies a binary digit can have only one of two possible values. These are often considered to be the two values, zero (0) and one (1). This can be compared to our more conventional decimal digits which can have any one of ten possible values (0, 1, 2, 3, 4, 5, 6, 7, 8, or 9).

The advantage of a bit is that it is easy to record or represent in a physical form using a variety of mechanical, electronic, magnetic, or optical devices. The representation of a bit requires only two possible states.

With most digital recording media a bit is assigned to a specific physical location. We can generally think of this physical location as a "fill in the blank" spot which can be marked in only one of two possible ways. It can be left blank which will present a value of zero or it can be "filled-in" or marked by some physical means to represent a value of one. A punch card is a simple mechanical medium for recording binary values. If a specific bit location is not punched, or in other words it is left blank, it represents the value zero. If the spot is marked by punching a hole it represents the value one. A bit location on a magnetic medium (disk, tape, banking cards, etc.) can be left unmagnetized to represent a value of zero or magnetized to represent a value of one. Bits are recorded on optical media by changing an optical characteristic such as reflectivity of the bit location.

Digital information is transmitted throughout a computer or communications system as a series of electrical pulses. A specific bit is represented by a time interval within the series which can be compared to a physical location on recording media. If no signal is turned on during the time interval, this is the off state; it represents a value of zero. On the other hand, if an electrical pulse or signal is present, the on state, it represents a value of one.

These examples represent a very valuable characteristic of binary representation. Numbers are recorded by simply marking a spot on the medium or turning on an electrical pulse during a specific time interval. This is a very robust process in that the numerical value is related only to the presence or absence of a mark, not the level of the mark.

The major limitation in using binary digits or bits is that each digit can have only two possible values whereas each decimal digit can have 10 different values. We overcome this limitation by using a series of bits which can then represent a larger range of values. The basic structure of a number consisting of 8 bits, or one byte as illustrated in Figure 3. This illustration shows how different pixel values and shades of gray are represented by different combinations of bit values. When the bits are clustered in this manner the maximum value represented by the non-zero state of each bit is determined by its position within the cluster. As we see, the first bit position on the right will have a value of 1, the second position a value of 2, and the third position a value of 4, etc. The value of the bit positions increases by a factor of two from one position to the next adjacent position. Each bit position in the non-zero state will have the value associated with its specific position. For example, if the second bit from the right is in the non-zero state it represents a value of two. If the second bit from the left is in the non-zero state it represents a value of 64.

The value of a cluster of bits, for example a byte, is simply the sum of the values of each bit which is in the non-zero state. We can gain a better appreciation of the characteristics and limitations of binary digits by comparing to the use of decimal digits. Think of a document with four blank spaces where numbers are to be filled in. Each space has a value associated with it depending on its position. The values increase by a factor of 10 from one position to the next. As we know, with decimal digits each blank can be filled in with any one of the 10 digits (0-9). The value of each digit is the product of the digit and the value associated with that specific digit position. The sum of the digit values is the value represented by the four digits.

The number of digits determines the range of numerical values that can be represented. For example:

1. one decimal digit can represent 10 values (0-9)
2. two decimal digits can represent 100 values (0-99)
3. three decimal digits can represent 1,000 values (0-999)

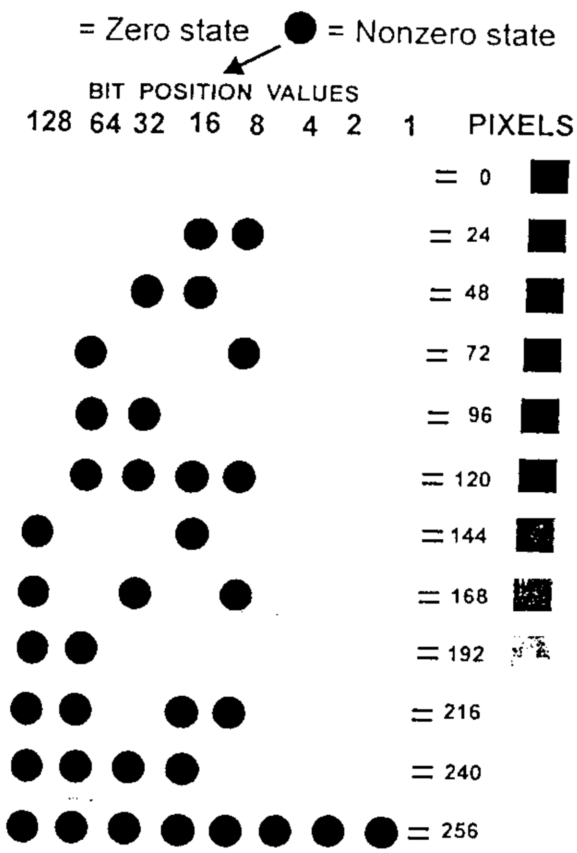

Figure 3. The structure of an 8 bit binary number (a byte) used to represent pixel values.

The range of numerical values that can be represented increases by a factor of 10 for each added digit.

A significant limitation to the use of bits is the range of values which can be represented. For example:

1. one binary bit can represent two values (0,1)
2. two binary bits can represent four values (0,1,2,3)
3. three binary bits can represent eight values (0,1,2,3,4,5,6, and 7)

The range of values which can be represented increases by a factor of two for each added bit. This is summarized in Table 1.

The significance of the number of bits per pixel is that it establishes the range of possible values for the pixel. The bit depth of a pixel determines the number of different shades of gray that can be represented in a gray scale image. However, in many applications it is not the number of shades of gray which is the issue. It is the range of numbers which is available to represent other characteristics such as x-ray receptor exposures, CT numbers, or MRI signal intensities. This is the contrast dynamic range associated with the image capture process.

C. Numerical Size

The numerical size, or number of bits required to represent an image, is a significant characteristic which must be considered when setting up digital image applications. In general, numerical size correlates with two major image quality

Table 1. Range of Pixel Values as Determined by Bit Depth

Bits Per Pixel	Range of Values
1	0-1
2	0-3
3	0-7
4	0-15
5	0-31
6	0-63
7	0-127
8	0-255
9	0-511
10	0-1,023
11	0-2,047
12	0-4,095
13	0-8,191
14	0-16,383
15	0-32,767
16	0-65,535

characteristics: detail and contrast. In general, these relationships will be described later. The other factor that must be considered is that digital image processing times, transmission times, and storage capacity required for images are affected by the image numerical size. The optimum numerical size for an image is one that provides adequate image quality for the specific clinical application without producing an unnecessary load on the digital system.

The numerical size of a basic digital image is the product of the number of pixels and the pixel bit depth. The number of pixels is the product of the two matrix dimensions. For the typical symmetrical matrix it is the square of the matrix size. The relationship of numerical size to typical matrix sizes is shown in Table 2 for the various modalities.

1) Image Compression

The relatively large numerical size of many medical images (especially the larger matrix sizes) can place a heavy load on the processing, transmission, and storage systems. It is usually possible to reduce the numerical size by the process of image compression. There are many hardware and software techniques which can be used to compress images into a smaller numerical size. Compression can be achieved by removing redundant information from an image, using more efficient digital encoding methods, or by reducing image quality. A compression technique is characterized by its compression ratio or the factor by which it reduces the numerical size. It is usually possible to apply some compression without reducing the quality of the image. This is described as lossless or reversible compression. and is limited to relatively low compression ratios. Higher levels of compression can be achieved with some loss of image quality. This is designated as lossy or non-reversible compression. One of the major issues being investigated at this time is the clinical impact of different types and levels of compression. The process and application of medical image compression is considered in a later chapter.

Table 2. The Numerical Size of Typical Images from the Various Modalities Assuming a 16 Bit Pixel Depth

Modality	Matrix	Numerical Size (bytes)
Gamma camera	128 × 128	32,768
MRI	256 × 200	102,400
CT	512 × 512	524,288
Radiography	2,048 × 2,048	8,388,608
Mammography	4,000 × 5,000	40,000,000

3. IMAGE DOMAINS

The basic digital image as described above is an array of numbers arranged in the spatial domain. This is the natural domain for image viewing and many acquisition methods create images directly in the spatial domain. It is also possible to represent images in other domains, especially the frequency domain. The spectrum of an image in the frequency domain is determined by the size of the objects in the image. Small objects and image detail are represented by high frequencies, whereas large objects are represented by low frequencies. There is a variety of image processing and analytic techniques which can be applied to images in the frequency domain. Also, the data for the reconstruction of some tomographic images like MRI are first acquired in the frequency domain.

It is a common practice to analyze and describe an imaging system's performance in terms of its ability to image the various spatial frequency components. The modulation transfer function (MTF) is the usual way of displaying frequency response. High-frequency response is reduced by the blurring associated with the imaging process.

An advantage of digitized images is that they can be readily transformed between the different domains. Transformations are especially useful for image reconstruction and compression.

A. Fourier Transform

The Fourier theorem states that a continuous function, such as a signal in the time domain or an analog image in the spatial domain, can be represented by the sum of a series of sine and cosine terms of increasing frequency. This can be applied to the two orthogonal directions in the typical two-dimensional image.

The Fourier transform is a mathematical process which can be easily applied to digitized images. One valuable characteristic of the Fourier transform is that it is reversible. It can be used to transform images from the spatial to the frequency domain or from the frequency to the spatial domain.

B. Wavelet Transforms

Wavelet transforms decompose an image into a collection of discrete wavelets.[1-3] This is done by performing inner products with functions which are scaled and translated versions of a mother wavelet. Image data is compared to the various scaled or shifted wavelets and coefficients are calculated. The coefficient value is an indication of the similarity between the image and a specific wavelet.

One advantage of wavelet analysis is that it preserves both spatial and frequency domain information.

Wavelets are a very useful method of representing images for a variety of analytical and compression procedures.

4. IMAGE CHARACTERISTICS

The five individual image characteristics (contrast sensitivity, detail, noise, artifacts, and geometry) introduced in the last chapter provide an appropriate framework for considering the effects of image digitization and the various digital functions identified in Figure 1.

A major advantage of a digitized image, especially compared to an analog image recorded on film, is that it can be processed to change many of its characteristics. Some form of image processing is used in every medical imaging modality to improve image quality and increase visibility of specific objects within the body.

5. CONTRAST SENSITIVITY AND IMAGE CONTRAST

Contrast sensitivity is a characteristic of an imaging process which determines the visibility of objects within the body in relationship to their physical contrast. Increasing contrast sensitivity causes lower contrast objects to become visible. Whereas contrast sensitivity is a characteristic of the total imaging process an image will also have specific contrast characteristics.

Contrast in an image is represented by the differences in the displayed characteristic such as brightness in an illuminated image display, film density in radiographs, shades of gray in printed opaque images, and colors. In digital images contrast is represented by the difference between the numerical values in different areas of an image. With respect to contrast, digital imaging has two major advantages over most forms of analog medical imaging. One is a wide contrast dynamic range and the other is the ability to change, and hopefully improve, the contrast characteristics of an image and the contrast sensitivity of the procedure by a variety of digital processing methods and windowing. These are illustrated in Figure 4 for a general digital radiographic application.

A. Contrast Dynamic Range

Analog images recorded on film have a limited contrast dynamic range which is often referred to as film latitude. The dynamic range or latitude is limited by the maximum optical density which the film can produce and the difficulty of viewing image regions recorded with high film densities. This makes it difficult to produce an optimum image of body sections which have a large range of tissue densities and thicknesses. Both chest radiography and mammography are limited by this characteristic. The limited dynamic range of film also increases the potential for exposure error. In film radiography the x-ray exposure to the receptor must be relatively accurate because of the limited dynamic range and the fact that once an image is recorded on film it cannot be changed to compensate for an exposure error. These restrictions do not generally apply to digitized images.

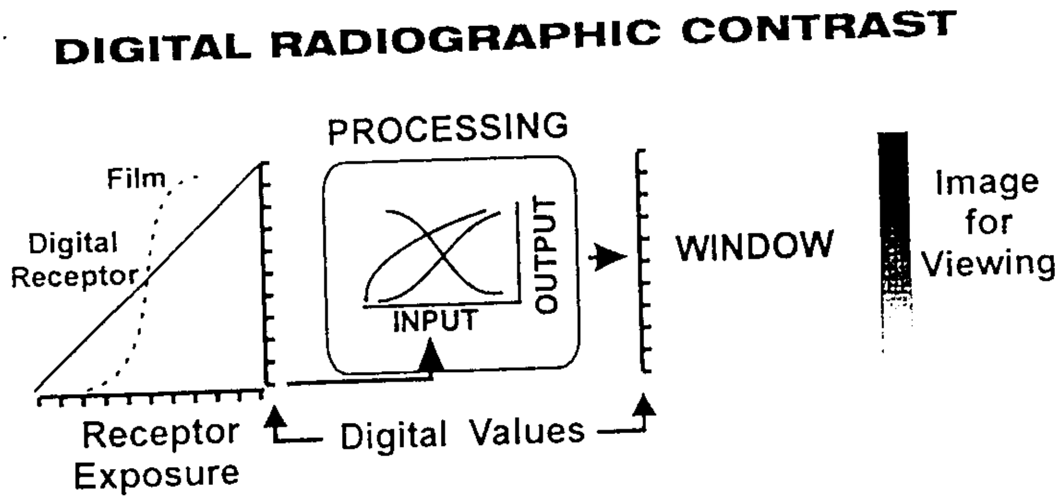

Figure 4. The elements of a digital radiographic system which have an effect on contrast.

There are two major factors that can limit the dynamic range of digital imaging systems. The first is the limitation of the image receptor system and the other is the limitation imposed by the pixel bit depth.

1) Receptor Dynamic Range

Most imaging systems which create a digitized image directly from electronic or optical (stimulable phosphor) receptors generally have a wide, and usually linear dynamic range compared to images recorded on film.

2) Pixel Bit Depth

The effective dynamic range of a digitized image is limited by the range of values associated with each pixel. This is determined by the bit depth. The selection of bit depth for most medical imaging applications is determined by the dynamic range requirements.

A wide dynamic range, for example 16 bits, might be required for an initial image. However, after appropriate processing the image can be recorded and viewed with a more restricted dynamic range like 8 bits. This will become more evident when we consider windowing and digital image processing.

B. Windowing

The ability to window is one of the major advantages in having images in a digital format. It makes it possible to capture images with a wide dynamic range and then select the appropriate segment of the range for contrast enhancement. This is illustrated in Figures 5 and 6. The window function is generally used to establish the relationship between a recorded digital image and the analog image for viewing. The window is the range of digital values which will be displayed as the shades of gray ranging from black to white. The range of digital values which will be displayed is determined by the settings of the two user adjustable window parameters, width and level.

1) Window Width

In principle the window width setting is a contrast control as shown in Figure 5. Decreasing the window width increases image contrast and contrast sensitivity for the imaging process.

Windowing is a major contributing factor to the high contrast sensitivity of computed tomography for the soft tissues in the body. The digital image in CT has a wide dynamic range covering materials ranging from low density air to dense bone. The soft tissues have close density values and cover only a small fraction of this range. If the entire dynamic range of the digital image was displayed with a wide window there would not be sufficient contrast sensitivity to distinguish the various soft tissues. However, by reducing the window width to a much smaller range the contrast sensitivity is increased and the different soft tissues become visible.

While using a small window enhances the contrast sensitivity for tissues within the window it reduces contrast sensitivity and visibility to a larger range of tissues which are represented by digital values outside of the window. In this example all pixel values below the window will be displayed as black. All pixel values

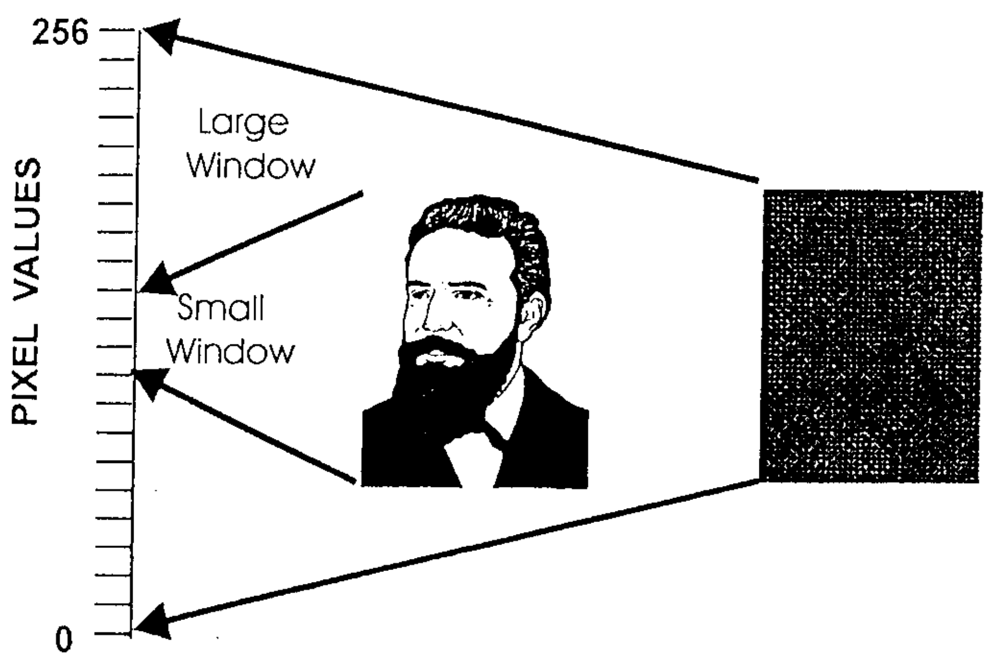

Figure 5. Reducing the window to a smaller range of pixel values increases image contrast.

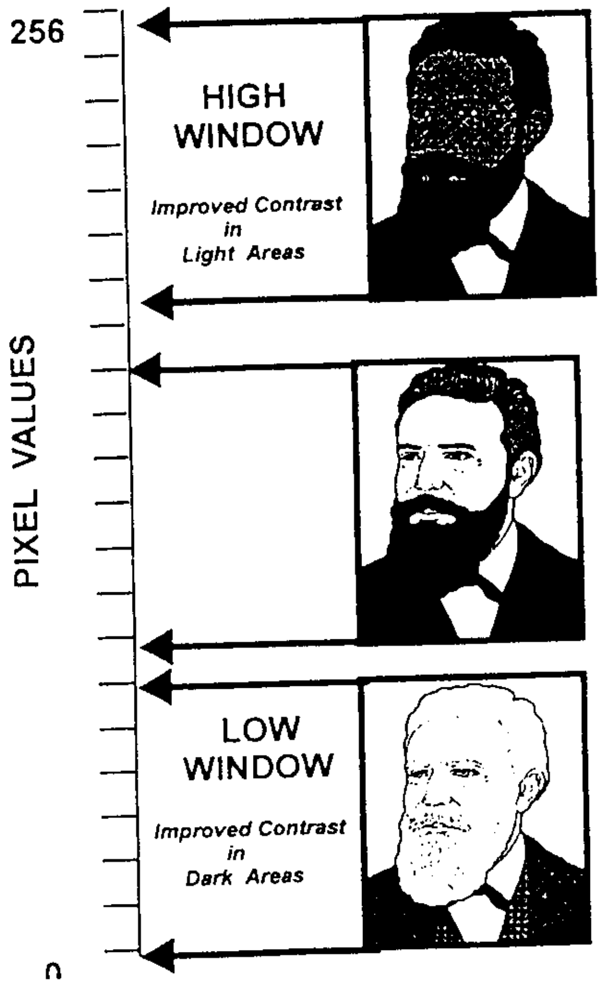

Figure 6. The effect on image contrast produced by changing the window level.

above the window will be displayed as white. If there is any contrast in the digital image in either of these regions it will not be visible in the displayed image.

2) Window Level

The window level control is used to position the window at any place within the digital dynamic range. This is illustrated in Figure 6. When the window is in a low position on the pixel value scale, all pixel values above the window will be displayed as white. However, the contrast sensitivity for structures represented by pixel values in this lower range is increased. When the window is positioned at the higher pixel values all pixels below the window will be displayed as black.

C. Contrast Processing

The contrast characteristics of a digital image can be readily changed by digital processing.[4,5] There is a variety of processing methods which can be used to change, and hopefully improve, the contrast and appearance of an image. A method which is frequently used for medical images is illustrated in Figure 7. This is a point-to-point method in which the value of each pixel in the original image is changed to a new value according to a predefined relationship. This can be implemented by the use of computer lookup tables (LUT) where pairs of original and new pixel values are stored. The relationship between the original and new values can be displayed graphically as a contrast curve shown in the illustration. The similarity between this curve and a film characteristic (H and D) curve should be noted. A contrast curve of this general shape can be used to give a digital image the same appearance as an image recorded on film and which might be more familiar to a viewer. However, the real value of digital processing is that the curve shape and position relative to the original image pixel value scale can be readily changed. In principle it is possible to have a variety of contrast curves each of which is optimized for a specific type of imaging procedure such as chest, skull, etc.

In digital radiography the position of the curve along the original image scale determines the effective receptor sensitivity. Sensitivity is increased by shifting the curve in the direction of lower values. This procedure can be used to compensate for exposure error in the recording of the original image.

D. Histogram Equalization

The distribution of pixel values in an image can be represented as a histogram which shows the number of pixels having each specific value. This would correspond to the distribution of brightness levels in a typical image. Most images will not have a uniform distribution of pixel values. Specific objects or predominant features such as light or dark areas will generally produce clustered pixel values. This results in some pixel values or brightness levels being somewhat under-utilized in the image.

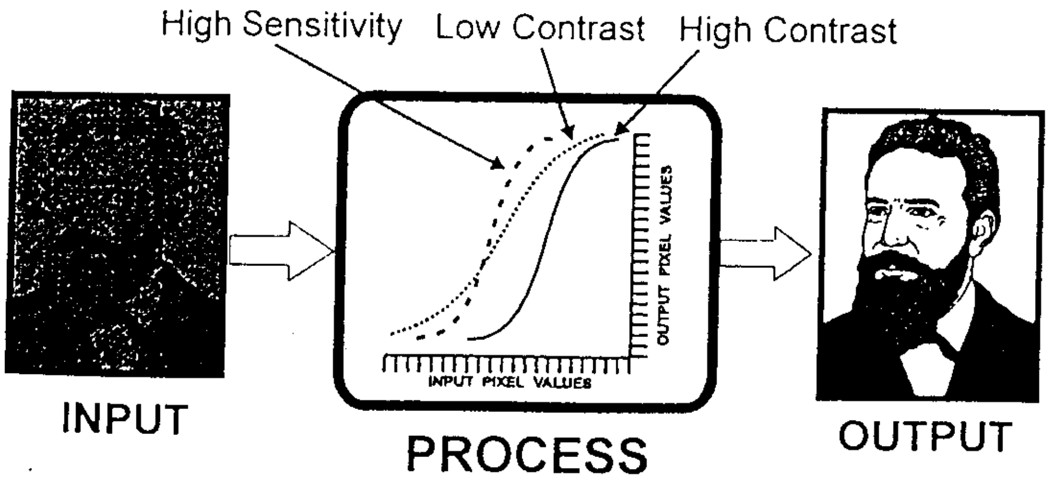

Figure 7. Digital image processing which can be used to change the contrast characteristics of an image.

The process of histogram equalization reassigns or shifts pixel values so that each pixel value or brightness is represented by the same number of pixels. However, the pixels retain their order with respect to the value or brightness of other pixels.

Histograms equalization can increase the visibility of certain objects within an image. It can be used to give a series of images the same general brightness and contrast characteristics.

6. IMAGE DETAIL

Visibility of anatomical detail or other small objects is limited by the blurring of the image which is an inherent part of all imaging procedures. However, the amount of blurring and the resulting visibility of detail varies from modality to modality and also depends on the selection of specific imaging technique or protocol factors within each modality.

The use of digital images can affect detail in two very different ways. The basic digital structure can limit or decrease detail. However, some image processing methods can be used to increase visibility of detail. Each of these will now be considered.

A. Digital Blurring

Digitizing an image is a blurring process because all detail within an individual pixel is blurred together and represented by a single pixel value. The size of a pixel determines the amount of blurring introduced by the digitizing process as illustrated in Figure 8. The actual pixel size is a good approximation of the equivalent blur value and is a useful parameter for comparing the effects of image digitization to other sources of blurring within various imaging systems.

The impact of pixel size on visibility of detail is determined by the pixel size in relationship to the size of the object being imaged. For that reason the pixel size must be evaluated in the object plane rather than the image plane. In x-ray projection imaging the relationship of pixel sizes between the object and image planes is determined by the amount of geometric magnification or the position of the object on the "s" scale.

The pixel size is the ratio of the field of view (FOV) in the object plane to the matrix size.

$$\text{Pixel Size (mm)} = \frac{\text{FOV (mm)}}{\text{Matrix Size (pixels)}}$$

Pixel size and the associated blurring is reduced and visibility of detail is increased by either increasing the matrix size or reducing the FOV.

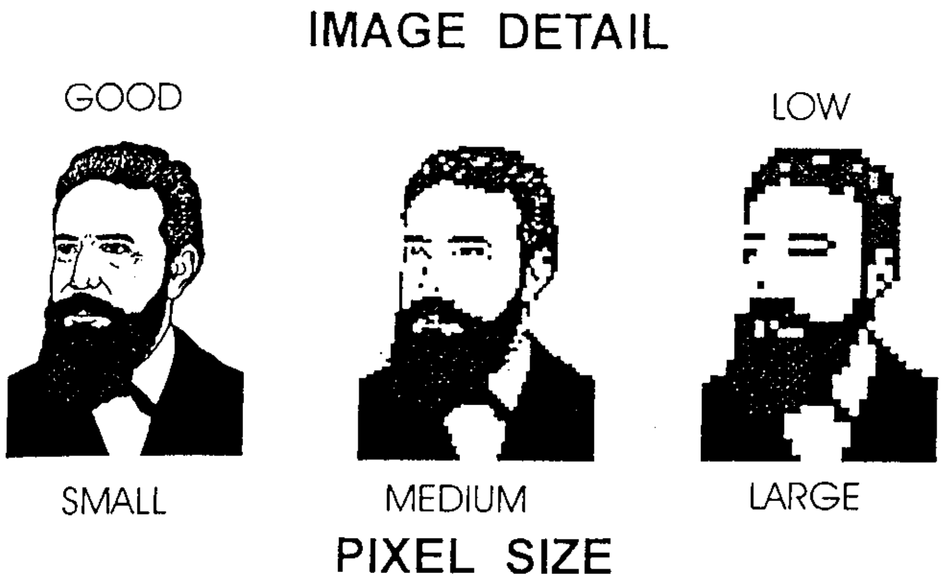

Figure 8. The loss of image detail produced by pixel blurring.

1) Matrix Size

In many medical imaging applications the matrix size is usually selectable within a range and is used to adjust pixel size. Matrix size is typically in binary multiples such as 128, 256, 512, 1,024, or 2,048 but other more optimized values are used in some applications like MRI. The maximum matrix size might be determined by the design of the technology for a specific imaging modality but is frequently limited by other considerations. The optimum matrix size is often dictated by the other blurring characteristics of the imaging system. It is not appropriate to use a large matrix to produce a small pixel which is much smaller than the blur values for other system components.

2) Field of View

The FOV is generally determined by the clinical requirements to cover a specific anatomical region. Reducing the FOV as much as possible is a practical approach to improving image detail. This reduces pixel size (blurring) without increasing the numerical size of the image.

B. Voxels

Tomographic imaging methods such as CT and MRI divide the slice of tissue into a matrix of volume elements or voxels. There is generally a one-to-one relationship between tissue voxels and image pixels although interpolation is sometimes used to create more pixels than there are voxels. With these imaging methods it is the voxel size rather than the pixel size that must be given the most consideration. It is the voxel size which has the most direct effect on image detail because a voxel is a three-dimensional blur due to slice thickness.

In MRI the voxel is the predominant source of blurring and limitation to image detail. In CT the voxel size is just one of the sources of blurring along with the detectors, focal spot, and possible blurring by some digital filter algorithms.

C. Imaging System Parameters

Visibility of detail is limited by the combined effect of all sources of blurring in the imaging system. This includes pixel size or voxel size for the digitized image. Table 3 lists some typical matrix sizes and FOVs used with the different imaging modalities. The calculated pixel sizes can be compared to the general range of blur values for the other components of the imaging systems.[6]

D. Digital Image Enhancement

Image detail is reduced by blurring. While it is not generally possible to "unblur" an image and restore lost detail it is possible to use digital processing to increase the visibility of detail in some images.[4,5] In reference to the frequency domain this is achieved by processing with a high-pass filter.

The basic approach to enhancing the visibility of image detail is to increase the contrast of small objects in relationship to the contrast of larger objects and areas within an image. There is a variety of digital processing algorithms for enhancing detail. Some are generally characterized as edge enhancement procedures. Edges and boundaries are forms of image detail and are represented by high-frequency components in the frequency domain.

We will now consider the blurred (unsharp) mask subtraction technique which is both useful in medical imaging applications and provides insight into the concept of detail enhancement. This is illustrated in Figure 9.

The first step is to blur a copy of the original image to create a mask. The mask is an image which retains the large object and area contrast but the contrast of the small objects and detail is removed by the blurring process. The second step is to

Table 3. Pixel Sizes in the Different Modalities

Modality	Matrix	FOV (cm)	Pixel Size (mm)
Gamma Camera	128	50	3.91
MRI	256	25	0.98
CT	512	25	0.49
Radiography	2,048	36	0.18
Mammography	4,000	18	0.05

subtract the mask from the original image. This subtraction reduces the large object and area contrast and leaves the smaller objects and detail on a more uniform background. This makes is possible to increase the contrast of small objects and detail without developing excessive area contrast. The blurred mask contains the low spatial frequency components of the image. When they are removed by the subtraction process, the high-frequency components or details are enhanced. The specific characteristics of the processed image can be controlled by adjusting the relative amplitude (gain) of the images before the subtraction process.

7. IMAGE NOISE

Although there are many potential sources of image noise the predominant source in x-ray imaging is the quantum noise produced by the random distribution of photons. There is a potential for increased quantum noise with some forms of digital radiography because the wide dynamic range permit the acquisition of images at low exposure levels. There can also be a difference in the noise level between digital and film radiography even at the same exposure level because of differences in receptor absorption efficiencies and other sources of noise in digital receptors.

The selection of pixel and voxel size usually has a significant effect on image noise. The noise is generally decreased by increasing the pixel or voxel size. In MRI, the increased voxel size produces a stronger RF signal and increases the signal-to-noise relationship. A larger voxel in CT absorbs more photons and reduces the statistical variation which is the source of the noise. In radiography and fluoroscopy a larger pixel averages the photons over a larger area and reduces the noise. In many digital image applications the selection of pixel or voxel size involves a compromise between image detail and image noise.

There are a variety of digital processing methods which can be used to reduce image noise. However, they all involve compromises with other image characteristics.

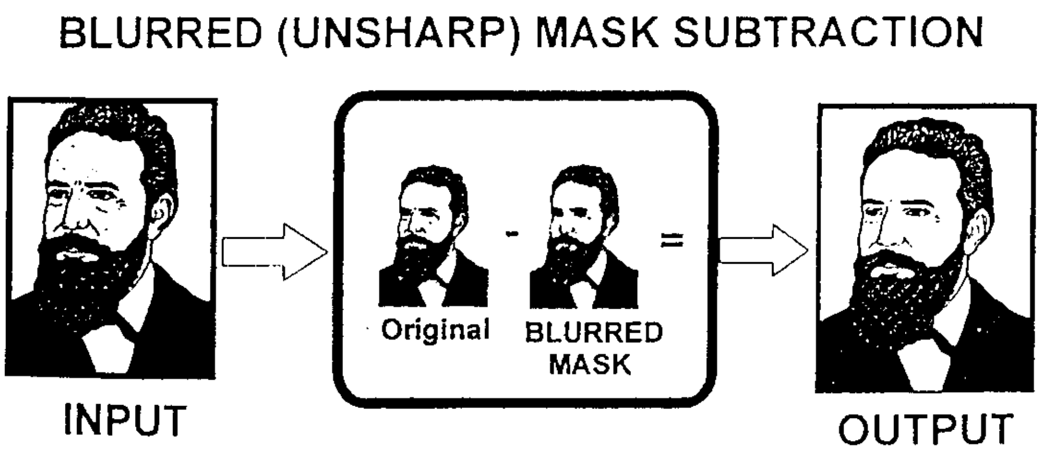

Figure 9. The blurred mask subtraction process for increasing image detail.

Noise is usually represented by high-frequency components in the frequency domain. Therefore, it can be reduced by filtering out the high frequency components with a so-called low-pass filter.

A. Noise Reduction by Digital Blurring

The noise, especially quantum noise, in an individual image can be decreased by blurring the image. This works because the noise is in the category of small objects and detail. As we have already seen, pixel size introduces some blurring which can be used to reduce noise. The next step is to average a cluster of pixels together by digital processing as shown in Figure 10. It is a common practice to use a weighted average where each individual pixel value is replaced by averaging its original value with the value of the neighboring pixels. The closest pixels are given a higher weighting in the averaging process.

Pixel averaging is a blurring process. Therefore, the use of this type of noise reduction must be considered in relationship to its effects on image detail.

B. Temporal Averaging

Digital processing can be used to reduce noise by averaging or integrating a series of images. For example, a series of individual fluoroscopic images which typically have a relatively high quantum noise level can be averaged to produce a resulting image with less noise. The effect is similar to that produced by the natural time response of the human visual system and the lag in some video systems. The application of this form of processing must be considered in relationship to its effect on temporal resolution and the observation of moving objects.

In MRI the averaging of a series of images (or acquired signals) is routinely used to reduce image noise. Here the trade-off is with acquisition time. The noise is reduced by increasing the number of images (signals) averaged together but this also increases the total time required to acquire the images.

8. OTHER DIGITAL IMAGE APPLICATIONS

This chapter is devoted primarily to the characteristics of digital images and processing methods which have an effect on the three basic image quality characteristics: contrast, detail, and noise. It is beyond the scope of this chapter to discuss the other applications of digitized images which contribute to contemporary medicine. The general applications of image archiving (storage and retrieval) and image transmission for teleradiology are addressed in later chapters. We will conclude this chapter with a brief overview of two additional applications.

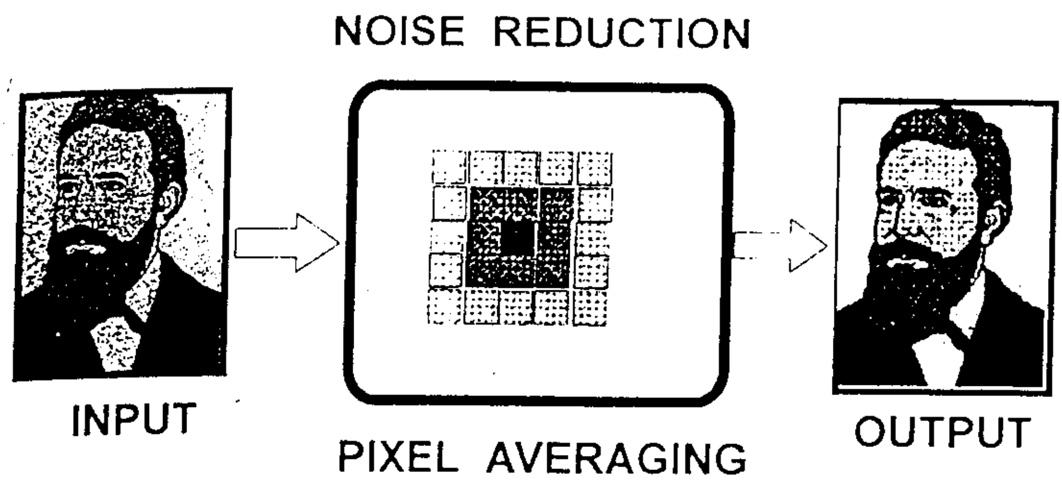

Figure 10. The reduction of noise by averaging a cluster of pixels.

A. Image Reconstruction

The development of computed tomography (CT) in the 1970s was a major milestone in medical imaging. In CT a digital tomographic image is mathematically reconstructed from data acquired during the scan process. Digital image reconstruction is also used in MRI, SPECT, and PET. These modalities would not be possible without digitized images.

It is now possible to produce three dimensional (3D) images of specific anatomical structures from sets of tomographic images.[7]

B. Image Analysis

Computer analysis of digitized images can be used to measure many characteristics. These range from very simple characteristics such as the size of objects within images to complex characteristics which can be used for computer aided diagnosis. While the computer is not a replacement for a skilled radiologist in the process of image interpretation it can provide valuable information which is not always obtained by direct human observations.

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