CHAPTER TWO

INDUSTRIAL X-RAY IMAGING SCHEME

2.1 THE NATURE OF X-RAYS

THE idea of using x-rays to produce visual images of the object body is referred to as x-ray imaging.

In 1895, Wilhelm Conrad Roentgen discovered that a highly penetrating radiation , emitted when high-speed .electrons strike a target. The x-rays produce fluorescence in certain materials, affect photographic film and travel in straight lines. Unlike particle radiations, they are not deflected by electric or magnetic fields. The penetrating ability of the radiation increases with increasing energy of the incident electrons. The intensity of x-ray beam, on the other hand, is proportional to the number of electrons per second striking the target.

After several years of study, it was established that x-radiation exhibits certain phenomena (interference,diffraction and polarization) which are only associated with waves.It was finally possible to determine the wavelengths, and these were found to be much shorter than the wavelengths of ultraviolet light.

An alternative theory of electromagnetic radiation, the quantum theory, pictures the radiation as the emission of distinct and separate "packets" of energy, known as quanta or photons . The energy of the photon is directly proportional to the frequency of the radiation. X-rays are penetrating because they consist of photons carrying a large amount of energy compared to, for example,photons of visible light.

The two most important properties of x-rays, namely,their penetrating ability and their effect on photographic film, led Roentgen to produce the very first image of the human hand. Thus a new era in the history of medicine had begun; more specifically,it was the birth of roentgenology, the science of recording images of the body using x-rays and providing a diagnosis from those images. Later, the term radiology emerged to describe the same idea.Today, the term imaging is commonly used to indicate any technique which uses some form of energy to produce visual images of an object. Such techniques include ultrasound [26], nuclear medicine [27], thermography [28] and the most recent, magnetic resonance imaging [29].

2.2 COMPONENTS OF THE IMAGING SCHEME

An x-ray imaging scheme consists of a number of components systematically arranged so that each one plays an important role in the production of the image. It is therefore mandatory that technologists understand how each of these components work and how they fit together in the imaging chain. This is of vital importance,since technologists are directly responsible for the safe operation of the equipment and the production of optimum image quality.

A typical x-ray imaging scheme (Figure 2.1)

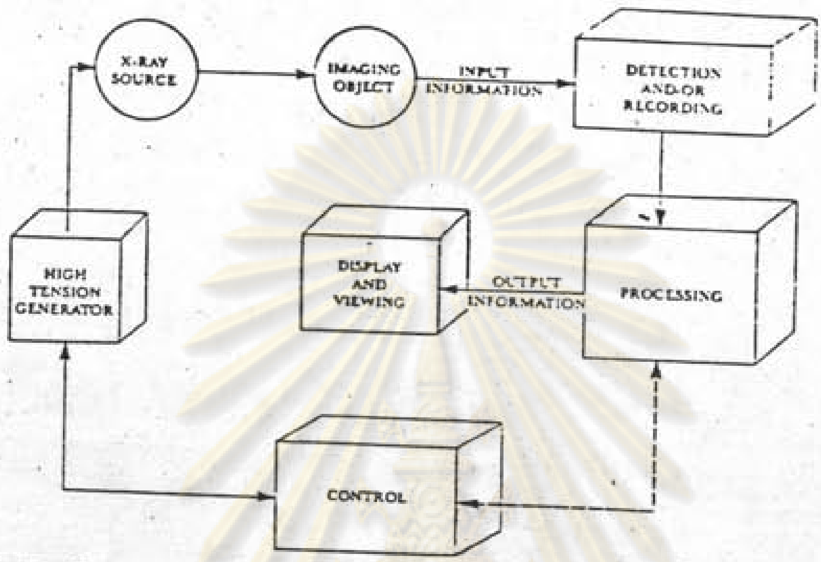

Figure 2.1. A typical arrangement of the components in an x-ray imaging scheme.

consists of the following components:

(a) An x-ray source.

(b) An imaging object.

(c) A detection and / or recording system.

(d) An image processing system.

(e) A display and viewing system.

(f) A high-voltage generator.

(g) A control unit.

Each of these will now be discussed briefly with a view of describing their general purpose in the total imaging scheme.

2.2.1 The X-ray Source

This is a special kind of glass tube with a highly sophisticated design. In the early days, x-rays were produced in gas-discharge tubes. Today, x-rays are produced in what is popularly referred to as the x-ray tube, an evacuated glass envelope consisting of two electrodes - an anode and a cathode.

In Figure 2.2, the basic features of an x-ray tube are shown. The electron stream is produced by thermionic emission from a heated filament. The electrons are then accelerated towards the target by a high potential difference applied across the tube. Upon striking the target, practically all of the kinetic energy of the electrons is transformed into heat. A very small fraction of energy (less than 1 %) appears in the form of x-rays. The unavoidable production of heat in the anode poses one of the major problems associated with the generation of x-rays.

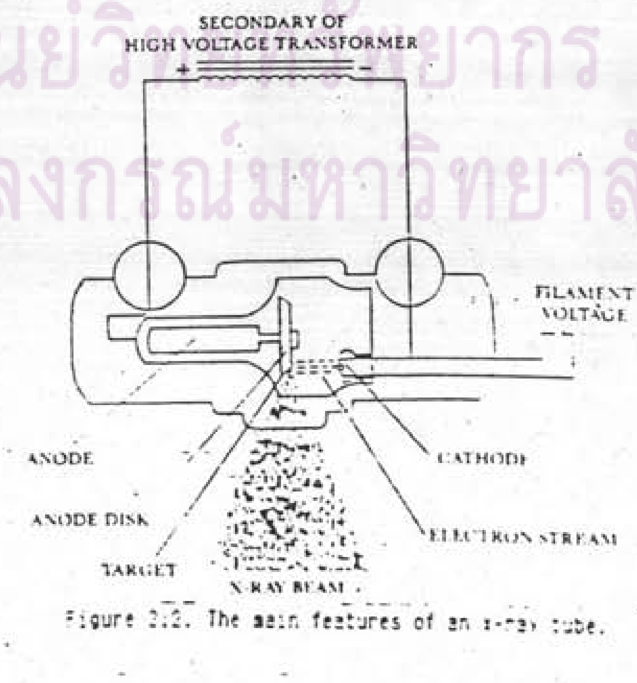

Figure 2.2. The main features of an x-ray tube.

2.2.2 The Imaging Object

The object in this context refers to the materials. The input information(Figure2.1) is derived from the materials. Transmitted x-rays are detected, processed, and later presented in some form for viewing and interpretation.

The fact that different layers in the materials absorb x-rays in different amounts is the fundamental basis for the formation of the image.

2.2.3 The Detection and Recording System

Transmitted x-rays must be received by some kind of detection system. In conventional radiography, the detector is a film or film/screen combination. In the latter, the screen converts x-rays into light and an image is formed on the film. This method of image formation uses less radiation compared to non-screen techniques.

In fluoroscopy, the image receptor (detector) is a fluorescent screen. Such a screen fluoresces when struck by x-rays. Today, the fluorecent screen is an essential element of a highly sophisticated image tube called the image intensifier. In this case, the image from the intensifier tube can be recorded onto magnetic tape and/or film.

In computed tomography the detector system can be either scintillation crystals coupled to photomultiplier tubes or gas-ionization detectors. These are special detectors which convert transmitted x-rays into electrical impulses. These impulses are then converted into digital data and stored onto magnetic tapes or disks. The digital data are then fed into a digital computer which performs mathematical operations on them to reconstruct an image.

The output image in this case can be recorded photographically so that a permanent record is available or it can be put on magnetic storage devices for reanalysis at some later time.

2.2.4 <u>The Image Processing System</u>

When transmitted x-rays fall upon a detector system, a "latent" image is formed. The image is rendered visible by subjecting it to a processing operation. Today, there are two kinds of processing systems.

The first kind is a chemical processing system, analogous to a photographic film processing system.

The second kind of processing is done by a computer which reconstructs images using special algorithms. This kind of processing demands special computer programs to solve both simple and complex mathematical equations.

2.2.5 <u>The Display and Viewing System</u>

In computed tomography equipment, the display and viewing system is available as a television monitor. The advantage of this method of display is that the operator can now control such factors as image brightness and contrast. The operator can also carry out a number of other operations on the image, such as magnification, measurements, and so on, In the future, such display and viewing consoles may become commonplace in most imaging departments.

2.2.6 The High-Voltage Generator

The high-voltage generator is a separate unit connected in such a way that it provides a high voltage to the x-ray tube. This voltage is mandatory for the production of x-rays.

2.2.7 The Control Unit

The control unit is perhaps one of the components in the total imaging scheme with which the technologist is in direct contact. The unit essentially controls several parameters in the imaging scheme. Such parameters include all factors which govern the production of both the quantity and quality of x-rays, as well as the duration of the x-ray exposure. For these reasons, and many more, a control panel is characteristic of the control unit.

The control panel consists of a number of knobs, push-button selectors, switches, display meters and so on. By manipulating the appropriate controls and selectors, the technologist sets up all the necessary factors for the examination. He may select the kilovoltage, the milliamperage, the duration of the exposure, which may be controlled by an electronic or automatic timer, and other factors as they relate to the examination. The display meters, on the other hand, indicate to the operator whether the selected factors are utilized when the exposure occurs and whether the system is improper working condition.

2.3 GEOMETRIC TOMOGRAPHY

In radiography, all structures in the object are superimposed on film. In some instances, the image may not clearly demonstrate distinct features of a particular area that may be of interest to the technologist. Fortunately, the technique of body-section radiography(BSR) can be used to demonstrate this area with a greater degree of constrast and detail than conventional techniques. In short, BSR is a procedure whereby special layers or planes of the body can be x-rayed by blurring out those structures laying above and below the layer or plane of interest.

In the developmental stages of BSR, other techniques were introduced to produce the same kind of imaging. These techniques(planigraphy,laminography, and stratigraphy) are all based essentially on the same principle.

Today, the general consensus is the use of the word tomography, from the Greek tomos(section) and tome(cut), to refer to any kind of imaging technique which demonstrates sections or "cuts" of the body.

More recently, another term, geometric tomography[30] has been used to describe the fundamental principles of body-section radiography and particularly to distinguish it from computed tomography.

Geometric tomography can perhaps be described in term of:

(a) Longitudinal tomography.

(b) Transverse axial tomography.

2.3.1 <u>Principles Of Longitudinal Tomography</u>

The term longitudinal is used in this context to specify the section of the body to be imaged, that is, longitudinal section or layer. This layer is parallel to the film.

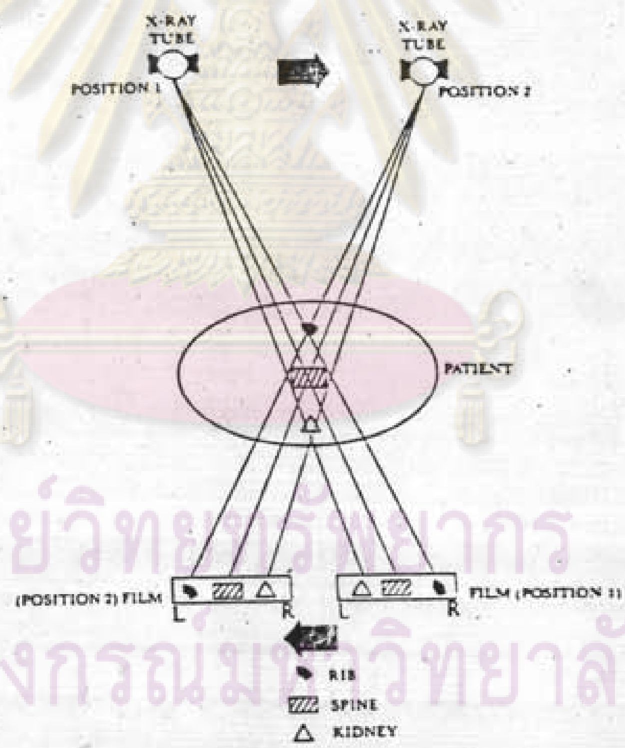

Figure 2.3 The principle of longitudinal geometric tomography.

The principle of longitudinal tomography is illustrated in its most fundamental form in Figure 2.3

The important point in the figure is the relative positions of the projected structures on film. When the x-ray tube is in position 1, the rib structure is projected on the right side of the film. When the tube moves to position 2, the rib is now projected on the left side of the film. The same applies to the kidney; that is , in tube position 1, the kidney is projected on the left side of the film, while in tube position 2, it is now projected on the right side of the film. The spine is the only structure which maintains the same position on the film regardless of the tube and film. This indicates that the spine would be imaged sharply and all other structures lying in the same plane as the spine would be imaged with equal clarity. The spine, then, is said to be the "plane of focus." All other structures which lie above and below the plane of focus are blurred.

The principle of longitudinal tomography involves simultaneous movement of the x-ray tube and film in opposite directions. This movement forms the basis of all tomography and determines the blurring characteristics and thickness of the section that can be imaged.

2.3.2 <u>Transverse Axial Tomography</u>

The fundamental objective of transverse axial tomography (TAT) is to produce selectively transverse sections (cross sections) of the body by rotating both object and film simultaneously and in the same direction.

Figure 2.4 shows a object positioned on a pedestal which is coupled to a turntable that holds the film. The coupling is such that the turntable and pedestal could rotate through 360^{o} in the same direction.

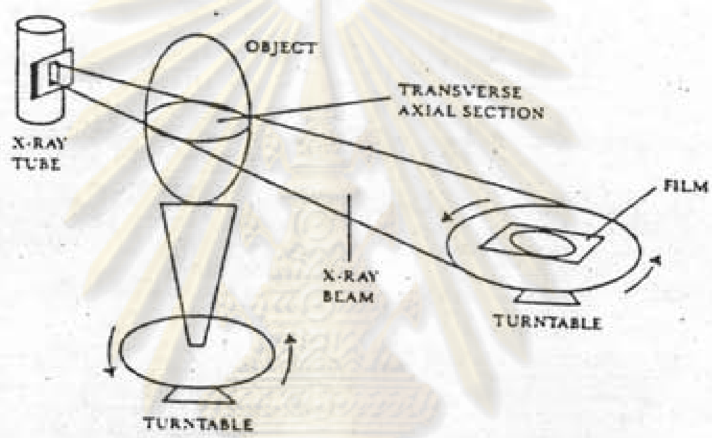

Figure 2.4 The principle of transverse axial tomography.

2.3.3 <u>Other Methods Of Tomography</u>

Conventional tomographic imaging with synchronous movement of x-ray tube and film cassette is a well-established technique in radiology. There are a few limitations imposed by this method (such as low contrast resolution and long exposure time), however, these are not serious since this method of imaging has been used successfully for decades. One such limitation (long exposure time) and others have prompted the need to investigate other forms of tomographic imaging. These method are discussed below.

2.3.4 Tomosynthesis

The word tomosynthesis implies that the tomographic image can be manipulated by electronic means. It is a term that evolved during the development and study of other forms of tomography. Whereas, a conventional tomographic image is processed chemically by developer and fixer solutions and cannot be changed or enhanced at this point(after wet processing),images obtained by methods of tomosynthesis can be manipulated electronically through the use of suitable image processing operations such as spatial frequency filtration, for example.

The method of tomosynthesis are few and they have not gained popularity and widespread use; therefore, only brief description will be given here.

The purpose of short exposure tomography can be traced back to the 1950s when Lindblom applied the technique to a machine called the blomograph. In 1968,Dummling proposed televised electronic tomography using conventional tomographic equipment with an image intensifier and television camera tube.This was followed by another technique called flashing tomosynthesis in which 24 stationary-anode x-ray tubes are used and which are all energized at the same time. Specially coded aperture are also used in this method.

Late in 1974, Weiss published a report on a system called cinetomosynthesis using the coded aperture principle. The quality of the image obtained with cinetomosynthesis is below acceptable limits and, therefore, it will not be described here.

more recently, another electronic tomographic technique, tomoscopy, was described by Sklebitz and Haendle(1983)[31] and their results published in the American Journal of Roentgenology.

2.4 <u>DIGITAL IMAGE PROCESSING</u>

2.4.1 <u>History</u>

The history of processing images by a digital computer (digital image processing) goes back several decades and its development continues to attract attention in anumber of areas.

Digital image processing may be regard as an interdisciplinary subject since it revolves around physics, mathematics, engineering and computer science. In therefore has a wide spectrum of applications, for example, it has been applied to problems in physics, biology, anatomy and physiology, weather forecasting, electron microscopy, criminology, industrial radiography and space studies.

Digital image processing had significant development at the Jet Propulsion Laboratory of the Carifornia Institute of Technology where it was used in space studies involving the challenge to put a man on the moon. The images that were sent back from unmanned craft such as Ranger, Surveyor and Mariner were all subject to digital image processing techniques. The processing of the poor and degraded images that were sent back not only enhanced them but restored them as well.

In general, the use of digital image processing in the space programme has had a significant impact on applications in other fields. More recently, digital image processing has found widespread application in medicine (32-48), where it has been applied successfully in techniques such as computed tomography, digital radiography, magnetic resonance imaging, nuclear medicine and ultrasound.

The increasing interest in digital image processing is primarily attributed to advance in micro-electronic technology and complex mathematics that can be carried out by a digital computer which has become more affordable.

2.4.2 <u>Image Representation</u>

2.4.2.1 <u>Analog Images</u>

To understand digital image processing, it is importance to realize that an image can be represented in a number of ways. Images can also be formed in several ways.

In photography, the image of an object is formed by focussing light rays on film. The film is then processed in specific chemical solutions to render the image visible. In radiography, when a beam of x-rays passes through a object, the transmitted x-rays (the x-ray image) are projected onto x-ray film. The film is then processed in chemical solutions to render it visible.

The two examples just given are images formed by the photochemical process. Other examples of visible images are pictures such as painting, drawing andoptical images. Images can also be formed by photoelectronic means. In this process the images can be represented as electrical signals.

Last but not least, images can also be represented as mathematical functions and by nonvisible means, such as temperature and pressure.

The images discussed so far are analog in form. This means that the information is continuously available in comparison to information which is available in discrete units, such as pulses. The popular sine wave is a classical representation of an analog signal. It varies continuously with time.

2.4.2.2 <u>Digital Images</u>

Digital image processing makes use of a digital computer so that any data going into the computer must first be converted into digital form(number). Therefore, analog information (analog images) must be change into digital information which be computer can use to process the data (Figure 2.5). This type of conversion is referred to as analog-to-digital conversion and it requires the use of an analog-to-digital converter (ADC).

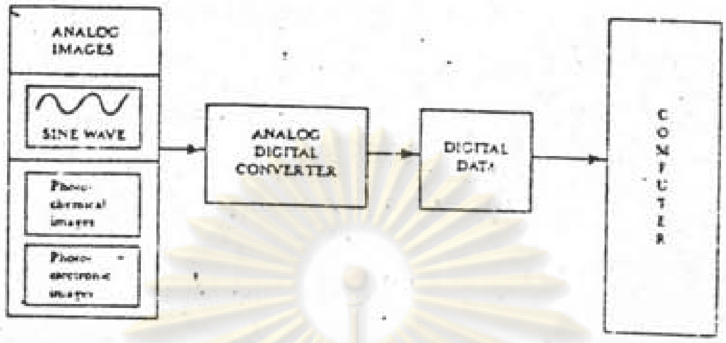

Figure 2.5 Block diagram of the conversion of analog information to digital data for input into a digital computer.

The computer then performs the necessary processing on the digital data and may display the results in digital form (that is, as a digital image) as shown in Figure 2.6

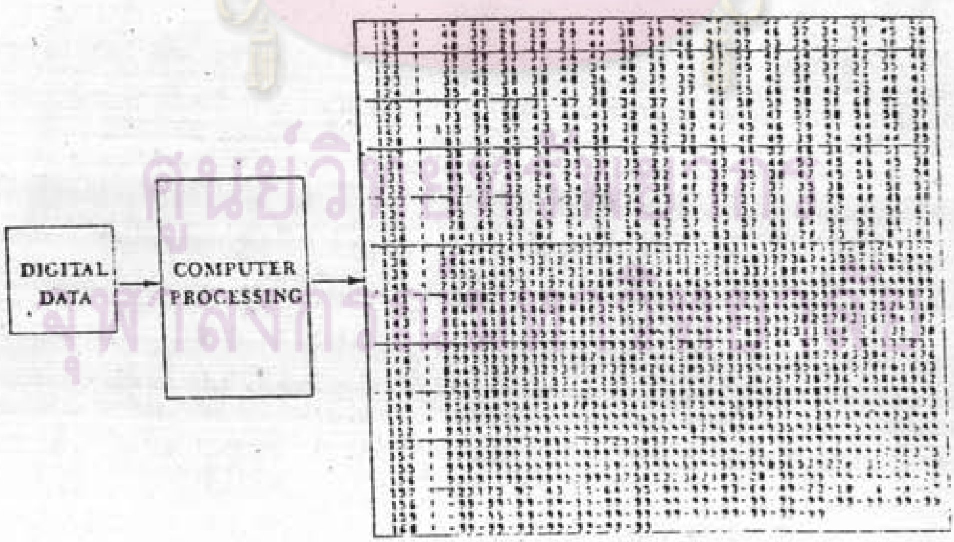

Figure 2.6 Data may be displayed in digital form

2.4.3 <u>Definition Of Digital Image Processing</u>

From the prevoius discussion, a formal basic definition of digital image processing can be given. Digital image processing is a technique whereby digital information(numerical data) is fed into a computer which performs specific operations(processing) on the data to generate images that may serve a more useful purpose.

By definition then, digital image processing has a number of advantages, since the computer-processed information can be manipulated in a number of ways to provide benefits with respect to image synthesis, image enhancement, storage and display.

2.4.4 <u>Steps In Digitizing An Image</u>

2.4.4.1 <u>Scanning</u>

How can the image formed by photochemical and photoelectronic means be converted into digital data? Consider an image formed by the photochemical process, a transparency(slide), for example. The first step in digitizing the picture involves dividing it up into an array of small regions. This process is known as scanning and it is illustrated in figure 2.7. Each small region in the picture is referred to as a pixel, a contraction for picture element.

2.4.4.2 <u>Sampling</u>

The next step involves a process called sampling. In sampling, the brightness of each pixel is measured by using special devices, such as a photomultiplier tube. In an example given by Cannon and Hunt[9] a small spot of light projected onto a transparency passes through it and is detected by a photomultiplier tube. The transmitted light intensity is converted into electrical impulses by the photomultiplier tube and these impulses are compared with the signal obtained when no slide is in the path of the original light. This process is sampling, where the relative brightness at each pixel is sampled or measured. This is illustrated in Figure 2.8. The process of sampling is done for the entire image.

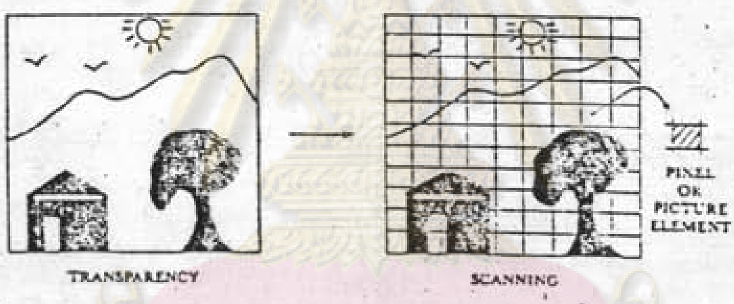

Figure 2.7 The process of scanning in digitizing an image. The transparency (picture) is divided up into a large number of picture elements or pixels.

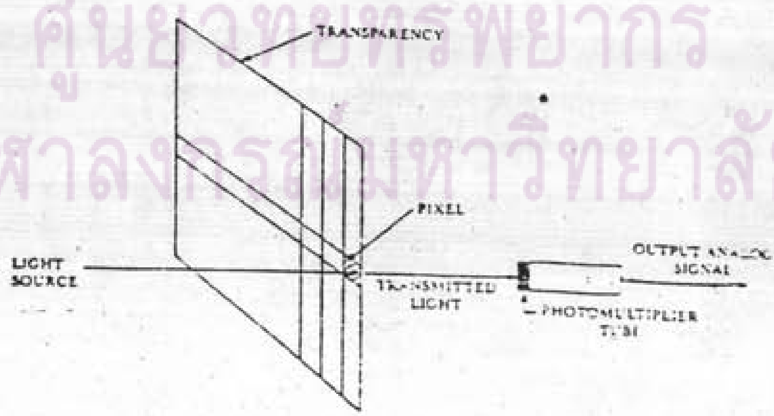

Figure 2.8 The process of image sampling. The brightness at each pixel location is measured with the aid of a photomultiplier tube or other suitable device.

2.4.4.3 <u>Quantization</u>

The third and final step in digitizing an image is quantization. Since the brightness values obtained during sampling are still analog signals, they must be converted into digital information before they can be fed into the computer. Quantization is a process whereby each brightness value is assigned a discrete number(0,a positive or a negative number) called a gray level. An image would therefore be made up of a range of numbers or gray levels. The total number of gray levels is called the gray scale. Figure 2.9 shows the process of quantization resulting in a four-level gray scale.

An image can have 2, 4, 8, 16, 32, 64, and so on, gray scale levels. In the case of two gray levels, the gray scale would show black and white only. In the case of 64 levels, one end of the gray scale would be black, the opposite end white, and shades of gray represented in the middle.

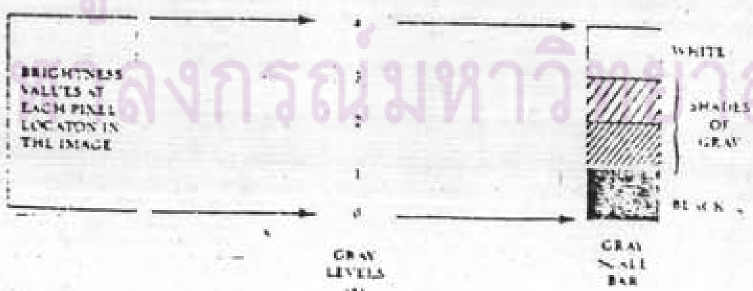

Figure 2.9

The process of quantization. Each measured brightness value is assigned an integer (0, + or − number) called a gray level. The gray levels can be transformed into a gray scale.

2.4.4.4 <u>Analog-to-Digital Conversion</u>

The process of analog-to-digital conversion is shown in Figure 2.10. The continuous analog signal is converted into a discrete digital representation by the analog-to-digital converter(ADC).

The faithful transformation of the analog signal to a digital signal depends on the "depth" of the ADC. An ADC with more "depth" will produce a more failthful reproduction of the original signal. The number of gray levels would also be higher. For example, a 2-bit ADC will generate 4(2^2) gray levels, while a 4-bit ADC will generate 16(2^4) gray levels. Most digital image processing systems including those used in medical or industrial imaging have at least 8-bit ADCs(2^8 = 256 gray levels) and 10-bit ADCs(2^{10} = 1024 gray levels).

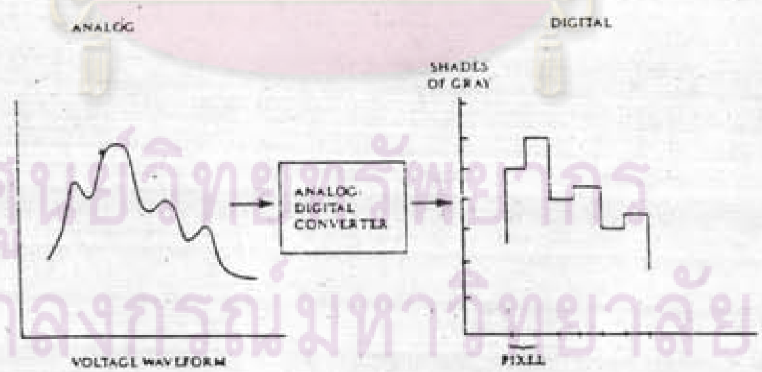

Figure 2.10 Analog-to-digital conversion. The continuous voltage waveform (left) is converted into a discrete or digital representation (right) by the ADC.

2.4.5 <u>Image Processing Operations</u>

The result of quantization gives an image which is now broken down into digitals. These digitals are then sent to the computer for processing.

The computer uses suitable programs to process the data to generate a desired result. Image processing operations include such techniques as manipulation, restoration, enhancement and analysis.

Image manipulation refers to image magnification and windowing. Image restoration involves algorithms to correct image noise and blurring. Image enhancement is a technique which improves the visual appearance of an image. Contrast stretching (performrd on individual pixels) and wieghted subtraction of image pairs are examples of image enhancement processing operations. Finally, image analysis includes those techniques which allow the operator to perform measurements (were and amplitude measurements within an image) and other quantitative analyses on the data.

Once processing is completed, the information can be stored onto magnetic disks or tapes or it can be displayed as a numerical printout or as an image on a television screen. In producing a television picture, it must be realized that the numerical(digital) data from the computer must be converted back to analog information.

2.4.6 <u>Digital-to-Analog-Conversion</u>

The conversion of digital information to analog form is accomplished by a digital-to-analog converter (DAC). This conversion is illustrated in Figure 2.11. Note that the analog signal obtained is not exactly the same as the original signal (Figure 4.10). There is some loss of detail.

This analog signal goes to the television monitor (an analog device) and plays a role in generating the television picture.

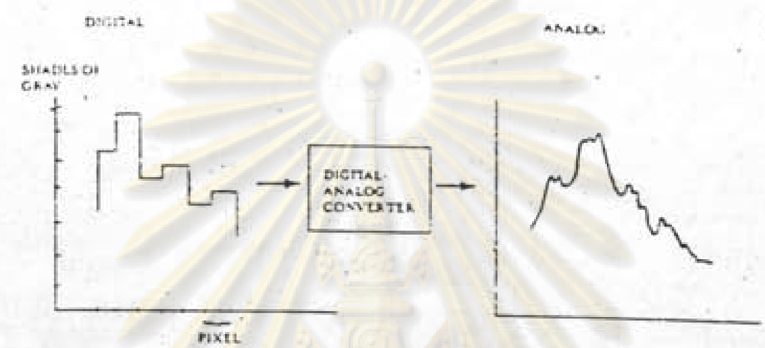

Figure 2.11 Digital-to-analog conversion. The analog signal is not reproduced faithfully as the original signal Figure 2.10 because of a loss of detail.