## PREVIEW

Interest in digital image processing methods stems from two principal application areas: improvement of pictorial information for human interpretation, and processing of image data for tasks such as storage, transmission, and extraction of pictorial information.

An image may be defined as a two-dimensional function, $f(x, y)$, where $x$ and $y$ are spatial (plane) coordinates, and the amplitude of $f$ at any pair of coordinates $(x, y)$ is called the intensity or gray level of the image at that point. When $x$, $y$, and the intensity values of $f$ are all finite, discrete quantities, we call the image a digital image. The field of digital image processing refers to processing digital images by means of a digital computer. Note that a digital image is composed of a finite number of elements, each of which has a particular location and value. These elements are called picture elements, image elements, pels, and pixels. Pixel is the term used most widely to denote the elements of a digital image.

## EXAMPLES OF FIELDS THAT USE DIGITAL IMAGE PROCESSING

One of the simplest ways to develop a basic understanding of the extent of image processing applications is to categorize images according to their source (e.g., X-ray, visual, infrared, and so on). The principal energy source for images in use today is the **electromagnetic energy spectrum**. Other important sources of energy include **acoustic**, ultrasonic, and **electronic** (in the form of electron beams used in electron microscopy). **Synthetic** images, used for modeling and visualization, are generated by computer.

Images based on radiation from the EM spectrum are the most familiar, especially images in the X-ray and visual bands of the spectrum. Electromagnetic waves can be conceptualized as propagating sinusoidal waves of varying wavelengths, or they can be thought of as a stream of massless particles, each traveling in a wavelike pattern and moving at the speed of light. Each massless particle contains a certain amount (or bundle) of energy. Each bundle of energy is called a photon. If spectral bands are grouped according to energy per photon, we obtain the spectrum shown in Fig. 1, ranging from gamma rays (highest energy) at one end to radio waves (lowest energy) at the other. The bands are shown shaded to convey the fact that bands of the EM spectrum are not distinct, but rather transition smoothly from one to the other.

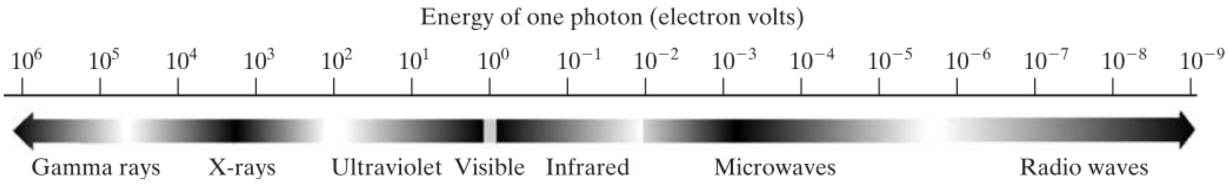

*Figure 1: The electromagnetic spectrum arranged according to energy per photon.*

unlike humans, who are limited to the visual band of the electromagnetic (EM) spectrum, imaging machines cover almost the entire EM spectrum, ranging from gamma to radio waves. They can operate on images generated by sources that humans are not accustomed to associating with images. These include ultrasound, electron microscopy, and computer-generated images.

## GAMMA-RAY IMAGING

Major uses of imaging based on gamma rays include nuclear medicine and astronomical observations. In nuclear medicine, the approach is to inject a patient with a radioactive isotope that emits gamma rays as it decays. Images are produced from the emissions collected by gamma-ray detectors. Fig. 2 shows a major modality of nuclear imaging called positron emission tomography (PET). In PET, the patient is given a radioactive isotope that emits positrons as it decays. When a positron meets an electron, both are annihilated and two gamma rays are given off. These are detected and a tomographic image is created using the basic principles of tomography. The image shown in Fig. 2 is one sample of a sequence that constitutes a 3-D rendition of the patient. This image shows a tumor in the brain and another in the lung, easily visible as small white masses.

*Figure 2: (b) PET image.*

We can also monitor nuclear reactor by collecting the gamma rays. Lastly, the gamma waves can be collected from the outer space for imaging in the field of astronomy.

## X-RAY IMAGING

X-rays for medical and industrial imaging are generated using an X-ray tube, which is a vacuum tube with a cathode and anode. The cathode is heated, causing free electrons to be released. These electrons flow at high speed to the positively charged anode. When the electrons strike a nucleus, energy is released in the form of X-ray radiation. The energy (penetrating power) of X-rays is controlled by a voltage applied across the anode, and by a current applied to the filament in the cathode. Figure 3 shows a familiar chest X-ray generated simply by placing the patient between an X-ray source and a film sensitive to X-ray energy. The intensity of the X-rays is modified by absorption as they pass through the patient, and the resulting energy falling on the film develops it, much in the same way that light develops photographic film

*Figure 3: Chest X-ray.*

In digital radiography, digital images are obtained by one of two methods: (1) by digitizing X-ray films; or; (2) by having the X-rays that pass through the patient fall directly onto devices (such as a phosphor screen) that convert X-rays to light. The light signal in turn is captured by a light-sensitive digitizing system.

Contrast medium can be injected to the human blood vessels to obtain images of blood vessels with enhanced contrast, called angiograms.

Another important use of X-rays in medical imaging is computerized axial tomography (CAT). Each CAT image is a “slice” taken perpendicularly through the patient. Numerous slices are generated as the patient is moved in a longitudinal direction.

Techniques similar to the ones just discussed, but generally involving higher energy X-rays, are applicable in industrial processes. These applications include: examining electronic circuit board, examining plastic assemblies or solid-propellant rocket motors for flaws in manufacturing. The X-ray imaging can also be used in astronomy.

## ULTRAVIOLET BAND IMAGING

Applications of ultraviolet “light” are varied. They include lithography, industrial inspection, microscopy, lasers, biological imaging, and astronomical observations. Ultraviolet light is used in fluorescence microscopy, one of the fastest growing areas of microscopy. The ultraviolet light itself is not visible, but when a photon of ultraviolet radiation collides with an electron in an atom of a fluorescent material, it elevates the electron to a higher energy level. Subsequently, the excited electron relaxes to a lower level and emits light in the form of a lower-energy photon in the visible (red) light region.

Fluorescence microscopy is an excellent method for studying materials that can be made to fluoresce, either in their natural form (primary fluorescence) or when treated with chemicals capable of fluorescing (secondary fluorescence).

## IMAGING IN THE VISIBLE AND INFRARED BANDS

Considering that the visual band of the electromagnetic spectrum is the most familiar in all our activities, it is not surprising that imaging in this band outweighs by far all the others in terms of breadth of application. The infrared band often is used in conjunction with visual imaging, so we have grouped the visible and infrared bands in this section for the purpose of illustration. We consider in the following discussion applications:

- light microscopy (pharmaceuticals and microinspection)
- astronomy,
- remote sensing

obtain and transmit images of the Earth from space, for purposes of monitoring environmental conditions on the planet. These images, usually, includes several bands in the visual and infrared regions of the spectrum.

- Industry

  A major area of imaging in the visible spectrum is in automated visual inspection of manufactured goods. A typical image processing task with products such as this is to inspect them for missing parts or anomalies.

- law enforcement.

  The applications in this category includes: first, process images of fingerprints either to enhance them or to find features that aid in the automated search of a database for potential matches. Second, the reading of the serial number on the money notes for the purpose of tracking and identifying currency bills. Third, automated license plate reading.

## MICROWAVE BAND IMAGING

The principal application of imaging in the microwave band is radar. The unique feature of imaging radar is its ability to collect data over virtually any region at any time, regardless of weather or ambient lighting conditions. Some radar waves can penetrate clouds, and under certain conditions, can also see through vegetation, ice, and dry sand. In many cases, radar is the only way to explore inaccessible regions of the Earth’s surface. An imaging radar works like a flash camera in that it provides its own illumination (microwave pulses) to illuminate an area on the ground and take a snapshot image. Instead of a camera lens, a radar uses an antenna and digital computer processing to record its images. In a radar image, one can see only the microwave energy that was reflected back toward the radar antenna.

## RADIO BAND IMAGING

the major applications of imaging in the radio band are in medicine and astronomy. In medicine, radio waves are used in magnetic resonance imaging (MRI). This technique places a patient in a powerful magnet and passes radio waves through the individual’s body in short pulses. Each pulse causes a responding pulse of radio waves to be emitted by the patient’s tissues. The location from which these signals originate and their strength are determined by a computer, which produces a two-dimensional image of a section of the patient. MRI can produce images in any plane.

## OTHER IMAGING MODALITIES

Although imaging in the electromagnetic spectrum is dominant by far, there are a number of other imaging modalities that are also important. Specifically, we discuss in this section acoustic imaging, electron microscopy, and synthetic (computer-generated) imaging.

Imaging using “sound” finds application in geological exploration, industry, and medicine. Geological applications use sound in the low end of the sound spectrum (hundreds of Hz) while imaging in other areas use ultrasound (millions of Hz).

Although ultrasound imaging is used routinely in manufacturing, the best known applications of this technique are in medicine, especially in obstetrics, where fetuses are imaged to determine the health of their development. A byproduct of this examination is determining the sex of the baby. Ultrasound images are generated using the following basic procedure:

1. The ultrasound system (a computer, ultrasound probe consisting of a source, a receiver, and a display) transmits high-frequency (1 to 5 MHz) sound pulses into the body.
2. The sound waves travel into the body and hit a boundary between tissues. Some of the sound waves are reflected back to the probe, while some travel on further until they reach another boundary and are reflected.
3. The reflected waves are picked up by the probe and relayed to the computer.
4. The machine calculates the distance from the probe to the tissue or organ boundaries using the speed of sound in tissue and the time of each echo’s return.
5. The system displays the distances and intensities of the echoes on the screen, forming a two-dimensional image.

Compared to the imaging modalities, Electron microscopes function as their optical counterparts, except that they use a focused beam of electrons instead of light to image a specimen. Electron microscopes are capable of very high magnification. While light microscopy is limited to magnifications on the order of 1000×, electron microscopes can achieve magnification of 10,000 × or more.

The area of 3-D modeling is the basis for many 3-D visualization systems (e.g., flight simulators). Because the original object is created in 3-D, images can be generated in any perspective from plane projections of the 3-D volume. Images of this type can be used for medical training and for a host of other applications, such as criminal forensics and special effects.

## BASIC PROCESSES INVOLVED IN IMAGE PROCESSING

The processes that can be applied to images for different purposes, and possibly with different objectives are:

1. **Image acquisition**
   Acquiring an image using specific type of sensing suitable with the energy source.
2. **Image enhancement**
   the process of manipulating an image so the result is more suitable than the original for a specific application.
3. **Image restoration**
   unlike enhancement, which is subjective, image restoration is objective, in the sense that restoration techniques tend to be based on mathematical or probabilistic models of image degradation. Enhancement, on the other hand, is based on human subjective preferences regarding what constitutes a “good” enhancement result
4. **Color image processing**
   Color can be used as the basis for extracting features of interest in an image.
5. **Wavelets**
   Wavelets are the foundation for representing images in various degrees of resolution
6. **Compression**

deals with techniques for reducing the storage required to save an image, or the bandwidth required to transmit it.

7. **Morphological processing**
   deals with tools for extracting image components that are useful in the representation and description of shape. So, instead of producing images as in the previous steps it produces image attributes.

8. **Segmentation**
   partitions an image into its constituent parts or objects.

9. **Feature extraction**
   almost always follows the output of a segmentation stage, which usually is raw pixel data, constituting either the boundary of a region or all the points in the region itself. Feature extraction consists of feature detection and feature description. For example, we might detect corners in a region, and describe those corners by their orientation and location.

10. **Image pattern classification**
    It is the process that assigns a label (e.g., “vehicle”) to an object based on its feature descriptors.

## COMPONENTS OF AN IMAGE PROCESSING SYSTEM

Two subsystems are required to acquire digital images. The first is a physical sensor that responds to the energy radiated by the object we wish to image. The second, called a digitizer, is a device for converting the output of the physical sensing device into digital form.

Specialized image processing hardware usually consists of the digitizer just mentioned, plus hardware that performs other primitive operations, such as an arithmetic logic unit (ALU), that performs arithmetic and logical operations in parallel on entire images. One example of how an ALU is used is in averaging images as quickly as they are digitized, for the purpose of noise reduction.

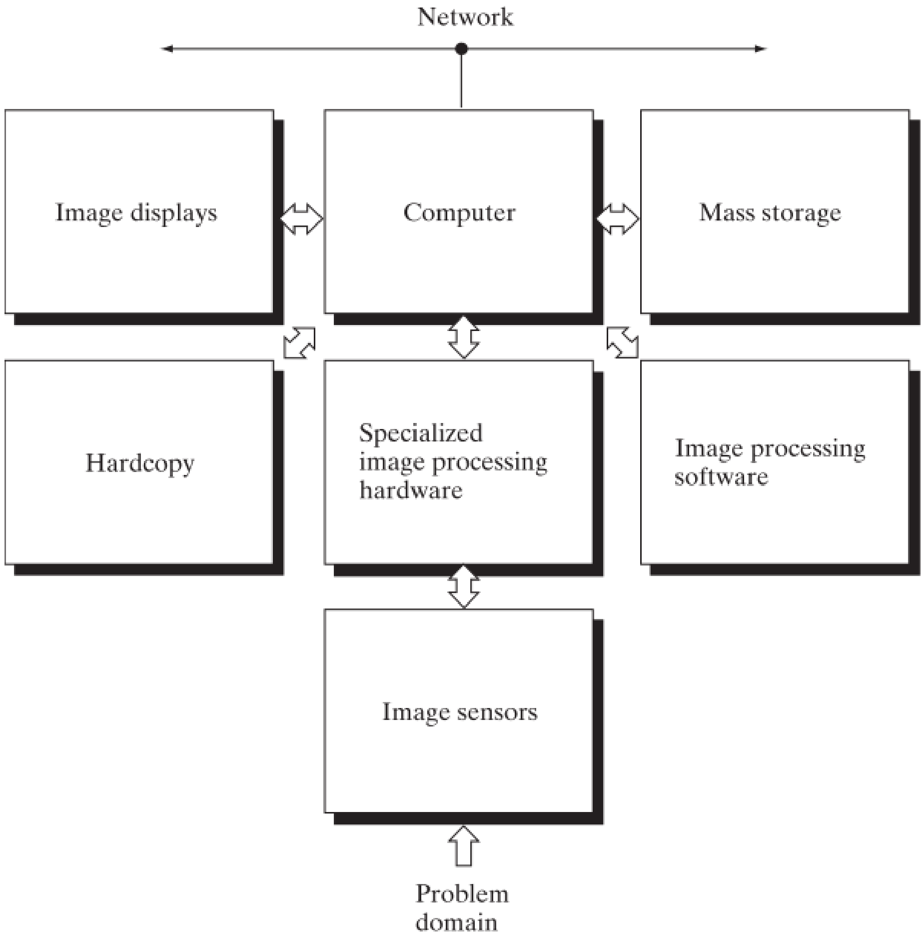

*Figure 4: Components of a general-purpose image processing system*

## References and further reading:

Digital Image Processing, 4th edition, Gonzalez, Rafael and Woods, Richard, 2018