Image Processing

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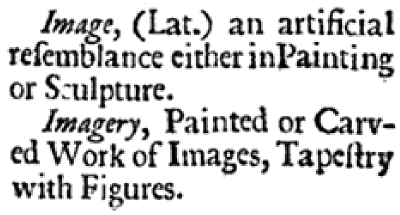
Contents

Articles

Introduction

Image

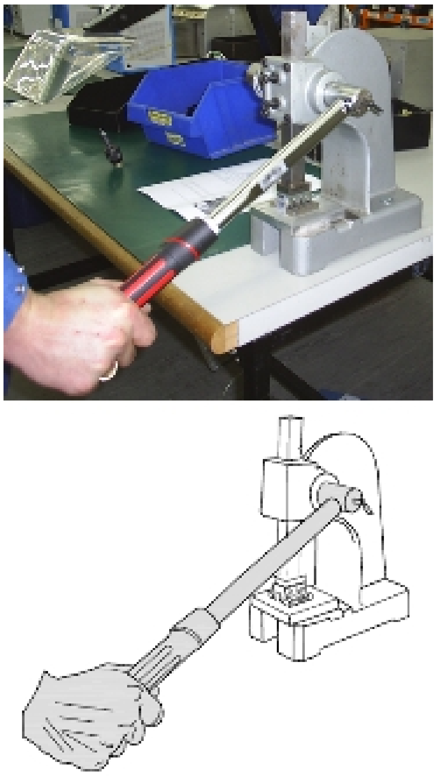
An **image** (from Latin *imago*) is an artifact, for example a two-dimensional **picture**, that has a similar appearance to some subject—usually a physical object or a person.


Image, (Lat.) an artificial resemblance either in Painting or Sculpture.
Imagery, Painted or Carved Work of Images, Tapestry with Figures.

Definition of *image* and *imagery*, from Thomas Blount's *Glossographia Anglicana Nova*, 1707.

Characteristics

Images may be two-dimensional, such as a photograph, screen display, and as well as a three-dimensional, such as a statue. They may be *captured* by optical devices—such as cameras, mirrors, lenses, telescopes, microscopes, etc. and natural objects and phenomena, such as the human eye or water surfaces.



The top image is captured using photography. The bottom image is rendered. Images are produced by capturing or rendering.

The word *image* is also used in the broader sense of any two-dimensional figure such as a map, a graph, a pie chart, or an abstract painting. In this wider sense, images can also be *rendered* manually, such as by drawing, painting, carving, rendered automatically by printing or computer graphics technology, or developed by a combination of methods, especially in a pseudo-photograph.

A volatile image is one that exists only for a short period of time. This may be a reflection of an object by a mirror, a projection of a camera obscura, or a scene displayed on a cathode ray tube. A fixed image, also called a hard copy, is one that has been recorded on a material object, such as paper or textile by photography or digital processes.

A mental image exists in an individual's mind: something one remembers or imagines. The subject of an image need not be real; it may be an abstract concept, such as a graph, function, or "imaginary" entity. For example, Sigmund Freud claimed to have dreamed purely in aural-images of dialogs. The development of synthetic acoustic technologies and the creation of sound art have led to a consideration of the possibilities of a sound-image made up of irreducible phonic substance beyond linguistic or musicological analysis.

A still image is a single static image, as distinguished from a moving image (see below). This phrase is used in photography, visual media and the computer industry to emphasize that one is not talking about movies, or in very precise or pedantic technical writing such as a standard.

A film still is a photograph taken on the set of a movie or television program during production, used for promotional purposes.

Moving image

A *moving image* is typically a movie (film), or video, including digital video. It could also be an animated display such as a zoetrope.

See also

- Cinematography
- Mental image
- Painting
- Photography

External links

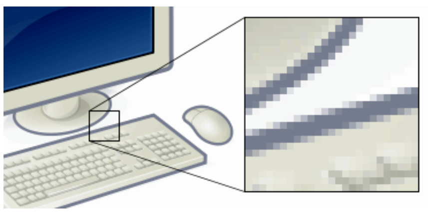
- The B-Z Reaction: The Moving or the Still Image? [1]
- FACE: Friends of Active Copyright Education [2]
- Library of Congress - Format Descriptions for Still Images [3]

References

[1] http://www.apple.com/science/insidetheimage/bzreaction/
[2] http://www.csusa.org/face/home.htm
[3] http://www.digitalpreservation.gov/formats/fdd/still_fdd.shtml

Pixel

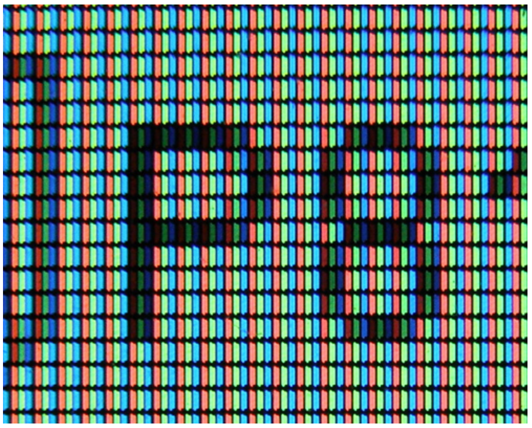
In digital imaging, a **pixel** (or **picture element**[1]) is a single point in a raster image. The pixel is the smallest addressable screen element; it is the smallest unit of picture that can be controlled. Each pixel has its own address. The address of a pixel corresponds to its coordinates. Pixels are normally arranged in a 2-dimensional grid, and are often represented using dots or squares. Each pixel is a sample of an original image; more samples typically provide more accurate representations of the original. The intensity of each pixel is variable. In color image systems, a color is typically represented by three or four component intensities such as red, green, and blue, or cyan, magenta, yellow, and black.



This example shows an image with a portion greatly enlarged, in which the individual pixels are rendered as little squares and can easily be seen.

In some contexts (such as descriptions of camera sensors), the term *pixel* is used to refer to a single scalar element of a multi-component representation (more precisely called a *photosite* in the camera sensor context, although the neologism *sensel* is also sometimes used to describe the elements of a digital camera's sensor),[2] while in others the term may refer to the entire set of such component intensities for a spatial position. In color systems that use chroma subsampling, the multi-component concept of a pixel can become difficult to apply, since the intensity measures for the different color components correspond to different spatial areas in a such a representation.

The word *pixel* is based on a contraction of *pix* ("pictures") and *el* (for "element"); similar formations with *el* for "element" include the words: voxel[3] and texel.[3]



A photograph of sub-pixel display elements on a laptop's LCD screen

Etymology

The word "pixel" was first published in 1965 by Frederic C. Billingsley of JPL (in Pasadena, CA), to describe the picture elements of video images from space probes to the Moon and Mars. However, Billingsley did not coin the term himself. Instead, he got the word "pixel" from Keith E. McFarland, at the Link Division of General Precision in Palo Alto, who did not know where the word originated. McFarland said simply it was "in use at the time" (circa 1963).[4]

The word is a combination of *picture* and *element*, via *pix*. The word *pix* appeared in *Variety* magazine headlines in 1932, as an abbreviation for the word *pictures*, in reference to movies.[5] By 1938, "pix" was being used in reference to still pictures by photojournalists.[4]

The concept of a "picture element" dates to the earliest days of television, for example as "Bildpunkt" (the German word for *pixel,* literally *picture point*) in the 1888 German patent of Paul Nipkow. According to various etymologies, the earliest publication of the term *picture element* itself was in *Wireless World* magazine in 1927,[6] though it had been used earlier in various U.S. patents filed as early as 1911.[7]

Some authors explain *pixel* as *picture cell,* as early as 1972.[8] In video processing, *pel* is often used instead of *pixel*.[9] For example, IBM used it in their Technical Reference for the original PC.

Words with similar etymologies

- Texel (texture element) and luxel (lux element) are words used to describe a pixel when it is used in specific context (texturing and light mapping respectively)
- A voxel is a *volume element*, the 3D analogue of a 2D pixel.
- Surfels (surface elements) have the same naming pattern as pixels, but share more similarities with shrunken triangles than expanded pixels.

Technical

A pixel does not need to be rendered as a small square. This image shows alternative ways of reconstructing an image from a set of pixel values, using dots, lines, or smooth filtering.

A pixel is generally thought of as the smallest single component of a digital image. The definition is highly context-sensitive. For example, there can be "printed pixels" in a page, or pixels carried by electronic signals, or represented by digital values, or pixels on a display device, or pixels in a digital camera (photosensor elements). This list is not exhaustive, and depending on context, there are several terms that are synonymous in particular contexts, such as pel, sample, byte, bit, dot, spot, etc. The term "pixels" can be used in the abstract, or as a unit of measure, in particular when using pixels as a measure of resolution, such as: 2400 pixels per inch, 640 pixels per line, or spaced 10 pixels apart.

The measures dots per inch (dpi) and pixels per inch (ppi) are sometimes used interchangeably, but have distinct meanings, especially for printer devices, where dpi is a measure of the printer's density of dot (e.g. ink droplet) placement.[10] For example, a high-quality photographic image may be printed with 600 ppi on a 1200 dpi inkjet printer.[11] Even higher dpi numbers, such as the 4800 dpi quoted by printer manufacturers since 2002, do not mean much in terms of achievable resolution.[12]

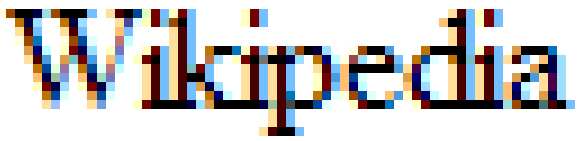
The more pixels used to represent an image, the closer the result can resemble the original. The number of pixels in an image is sometimes called the resolution, though resolution has a more specific definition. Pixel counts can be expressed as a single number, as in a "three-megapixel" digital camera, which has a nominal three million pixels, or as a pair of numbers, as in a "640 by 480 display", which has 640 pixels from side to side and 480 from top to bottom (as in a VGA display), and therefore has a total number of 640 × 480 = 307,200 pixels or 0.3 megapixels.

The pixels, or color samples, that form a digitized image (such as a JPEG file used on a web page) may or may not be in one-to-one correspondence with screen pixels, depending on how a computer displays an image. In computing, an image composed of pixels is known as a *bitmapped image* or a *raster image*. The word *raster* originates from television scanning patterns, and has been widely used to describe similar halftone printing and storage techniques.

Sampling patterns

For convenience, pixels are normally arranged in a regular two-dimensional grid. By using this arrangement, many common operations can be implemented by uniformly applying the same operation to each pixel independently. Other arrangements of pixels are also possible, with some sampling patterns even changing the shape (or kernel) of each pixel across the image. For this reason, care must be taken when acquiring an image on one device and displaying it on another, or when converting image data from one pixel format to another.

For example:



Text rendered using Cleartype

- LCD screens typically use a staggered grid, where the red, green, and blue components are sampled at slightly different locations. Subpixel rendering is a technology which takes advantage of these differences to improve the rendering of text on LCD screens.
- Some digital cameras use a Bayer filter, resulting in a regular grid of pixels where the *color* of each pixel depends on its position on the grid.
- A clipmap uses a hierarchical sampling pattern, where the size of the support of each pixel depends on its location within the hierarchy.
- Warped grids are used when the underlying geometry is non-planar, such as images of the earth from space.[13]
- The use of non-uniform grids is an active research area, attempting to bypass the traditional Nyquist limit.[14]

- Pixels on computer monitors are normally "square" (this is, having equal horizontal and vertical sampling pitch); pixels in other systems are often "rectangular" (that is, having unequal horizontal and vertical sampling pitch – oblong in shape), as are digital video formats with diverse aspect ratios, such as the anamorphic widescreen formats of the CCIR 601 digital video standard.

Display resolution vs. native resolution in computer monitors

Computers can use pixels to display an image, often an abstract image that represents a GUI. The resolution of this image is called the display resolution and is determined by the video card of the computer. LCD computer *monitors* also use pixels to display an image, and have a native resolution. Each pixel is made up of triads, with the number of these triads determining the native resolution. On some CRT monitors, the beam sweep rate may be fixed, resulting in a fixed native resolution. Most CRT monitors do not have a fixed beam sweep rate, meaning they don't have a native resolution at all - instead they have a set of resolutions that are equally well supported.

To produce the sharpest images possible on an LCD, the user must ensure the display resolution of the computer matches the native resolution of the monitor. On a CRT with a fixed beam sweep rate, you are required to use the native resolution. On a CRT without this restriction, you may use any resolution supported by the monitor that matches the monitor's physical aspect ratio and it will look fine. If the aspect ratio of the physical display and the selected resolution are different, many different things can happen. On some LCDs, the monitor will stretch or squash the image to fill the entire display. This can result in the image appearing blurry or jagged.

On others, the aspect ratio will be maintained while expanding the image to fit the display, resulting in black bars on the top or sides of the image. This can also result in the image appearing blurry or jagged, depending on the native resolution of the display and the selected resolution on the computer. For example, let's take the relatively common case of a full-screen application written assuming a 4:3 aspect ratio running on a 16:10 aspect ratio widescreen display. If the selected resolution were 1600×1200 and you were running it on a 1920×1200 display that maintains aspect ratio while expanding the image to fit, the image would not look blurry, because each pixel in the 1600×1200 image maps to exactly 1 pixel on the 1920×1200 display. If the selected resolution were 1280×960, the display would have to try to stretch the 960 pixels to fill 1200 pixels, which would mean each of the selected resolution pixels needs to take up 1.25 pixels on the physical display. Since this can't be done, the monitor uses some scheme to figure out how to distribute the colors from those 960 pixels to fill the 1200 pixels of the physical display. This mapping results in a blurry or jagged appearance. However, if the selected resolution were 800×600, you would be OK again, because 600 pixels can be expanded to 1200 pixels by having each pixel from the selected resolution take up 2 pixels on the physical display.

On yet other LCD monitors, if the selected resolution is less than the native resolution of the monitor, the monitor will display things in the selected resolution, with a black border around the edges.

Bits per pixel

The number of distinct colors that can be represented by a pixel depends on the number of bits per pixel (bpp). A 1 bpp image uses 1-bit for each pixel, so each pixel can be either on or off. Each additional bit doubles the number of colors available, so a 2 bpp image can have 4 colors, and a 3 bpp image can have 8 colors:

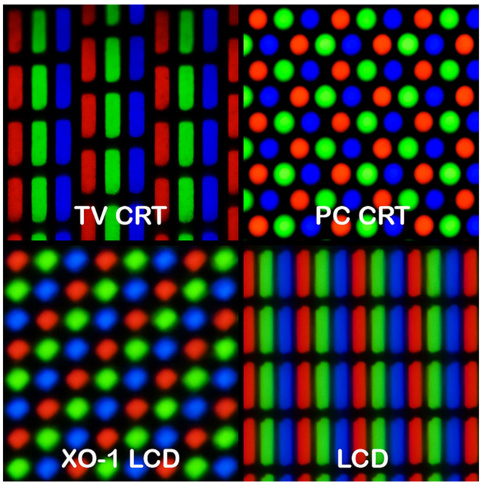
- 1 bpp, $2^1 = 2$ colors (monochrome)
- 2 bpp, $2^2 = 4$ colors
- 3 bpp, $2^3 = 8$ colors

...

- 8 bpp, $2^8 = 256$ colors
- 16 bpp, $2^{16} = 65{,}536$ colors ("Highcolor")
- 24 bpp, $2^{24} \approx 16.8$ million colors ("Truecolor")

For color depths of 15 or more bits per pixel, the depth is normally the sum of the bits allocated to each of the red, green, and blue components. Highcolor, usually meaning 16 bpp, normally has five bits for red and blue, and six bits for green, as the human eye is more sensitive to errors in green than in the other two primary colors. For applications involving transparency, the 16 bits may be divided into five bits each of red, green, and blue, with one bit left for transparency. A 24-bit depth allows 8 bits per component. On some systems, 32-bit depth is available: this means that each 24-bit pixel has an extra 8 bits to describe its opacity (for purposes of combining with another image).

Subpixels



Geometry of color elements of various CRT and LCD displays; phosphor dots in a color CRT display (top row) bear no relation to pixels or subpixels.

Many display and image-acquisition systems are, for various reasons, not capable of displaying or sensing the different color channels at the same site. Therefore, the pixel grid is divided into single-color regions that contribute to the displayed or sensed color when viewed at a distance. In some displays, such as LCD, LED, and plasma displays, these single-color regions are separately addressable elements, which have come to be known as *subpixels*. For example, LCDs typically divide each pixel horizontally into three subpixels. When the square pixel is divided into three subpixels, each subpixel is necessarily rectangular. In the display industry terminology, subpixels are often referred to as *pixels*, as they are the basic addressable elements in a viewpoint of hardware, and they call *pixel circuits* rather than *subpixel circuits*.

Most digital camera image sensors also use single-color sensor regions, for example using the Bayer filter pattern, and in the camera industry these are known as *pixels* just like in the display industry, not *subpixels*.

For systems with subpixels, two different approaches can be taken:

- The subpixels can be ignored, with full-color pixels being treated as the smallest addressable imaging element; or
- The subpixels can be included in rendering calculations, which requires more analysis and processing time, but can produce apparently superior images in some cases.

This latter approach, referred to as subpixel rendering, uses knowledge of pixel geometry to manipulate the three colored subpixels separately, producing a slight increase in the apparent resolution of color displays. While CRT displays also use red-green-blue masked phosphor areas, dictated by a mesh grid called the shadow mask, it would require a difficult calibration step to be aligned with the displayed pixel raster, and so CRTs do not currently use subpixel rendering.

Megapixel

A megapixel (MP) is 1 million pixels, and is a term used not only for the number of pixels in an image, but also to express the number of image sensor elements of digital cameras or the number of display elements of digital displays. For example, a camera with an array of 2048×1536 sensor elements is commonly said to have "3.1 megapixels" (2048 × 1536 = 3,145,728). The megapixel count is often used as a figure of merit, though it is only one of the figures that determines camera quality.

Digital cameras use photosensitive electronics, either charge-coupled device (CCD) or complementary metal–oxide–semiconductor (CMOS) image sensors, consisting of a large number of single sensor elements, each of which records a measured intensity level. In most digital cameras, the sensor array is covered with a patterned color filter mosaic having red, green, and blue regions in the Bayer filter arrangement, so that each sensor element can record the intensity of a single primary color of light. The camera interpolates the color information of neighboring sensor elements, through a process called demosaicing, to create the final image. These sensor elements are often called "pixels", even though they only record 1 channel (only red, or green, or blue) of the final color image. Thus, two of the three color channels for each sensor must be interpolated and a so-called *N-megapixel* camera that produces an N-megapixel image provides only one-third of the information that an image of the same size could get from a scanner. Thus, certain color contrasts may look fuzzier than others, depending on the allocation of the primary colors (green has twice as many elements as red or blue in the Bayer arrangement).

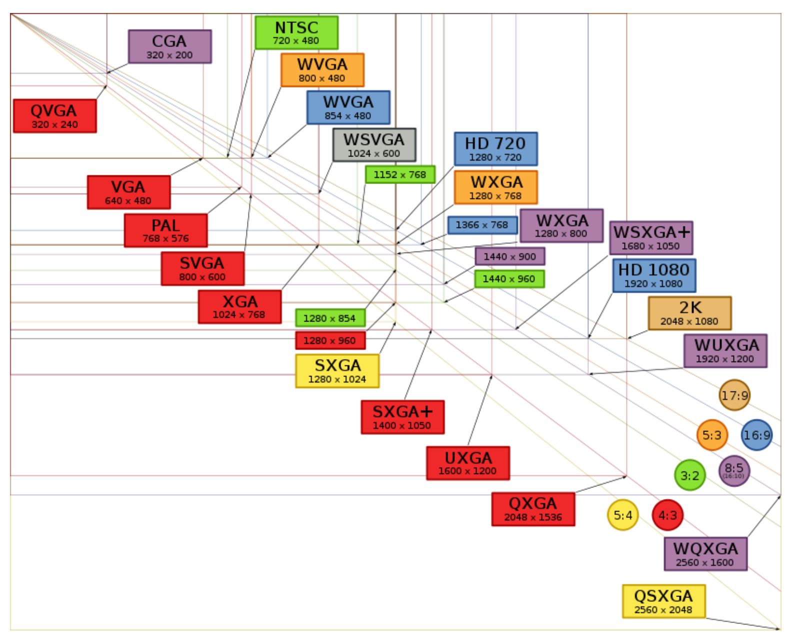
Standard display resolutions

The display resolution of a digital television or display device is the number of distinct pixels in each dimension that can be displayed. It can be an ambiguous term especially as the displayed resolution is controlled by all different factors in cathode ray tube (CRT) and flat panel or projection displays using fixed picture-element (pixel) arrays.

One use of the term “display resolution” applies to fixed-pixel-array displays such as plasma display panels (PDPs), liquid crystal displays (LCDs), Digital Light Processing (DLP) projectors, or similar technologies, and is simply the physical number of columns and rows of pixels creating the display (e.g., 1920×1200). A consequence of having a fixed grid display is that, for multi-format video inputs, all displays need a "scaling engine" (a digital video processor that includes a memory array) to match the incoming picture format to the display.

Note that the use of the word *resolution* here is misleading. The term “display resolution” is usually used to mean *pixel dimensions* (e.g., 1920×1200), which does not tell anything about the resolution of the display on which the image is actually formed. In digital measurement the display resolution would be given in pixels per inch. In analog measurement, if the screen is 10 inches high, then the horizontal resolution is measured across a square 10 inches wide. This is typically stated as “xxx lines horizontal resolution, per picture height.” Example: Analog NTSC and PAL TVs can typically display 480 (for NTSC) lines horizontal resolution, per picture height which is equivalent to 640 total lines from left-edge to right-edge.

Selected standard display resolutions include:



Display standards comparison

Name	Megapixels	Width x Height
CGA	0.064	320×200
EGA	0.224	640×350
VGA	0.3	640×480
SVGA	0.5	800×600
XGA	0.8	1024×768
SXGA	1.3	1280×1024
UXGA	1.9	1600×1200
WUXGA	2.3	1920×1200

See also

- Computer display standard
- Gigapixel image
- Image resolution
- Intrapixel and Interpixel processing
- Pixel advertising
- Pixel art
- Pixel art scaling algorithms
- Pixel aspect ratio
- Point (typography)
- Raster scan
- Rasterisation
- Vector graphics
- Voxel

External links

- A Pixel Is Not A Little Square [15]: Microsoft Memo by computer graphics pioneer Alvy Ray Smith.
- Pixels and Me [16]: Video of a history talk at the Computer History Museum.
- Square and non-Square Pixels [17]: Technical info on pixel aspect ratios of modern video standards (480i,576i,1080i,720p), plus software implications.

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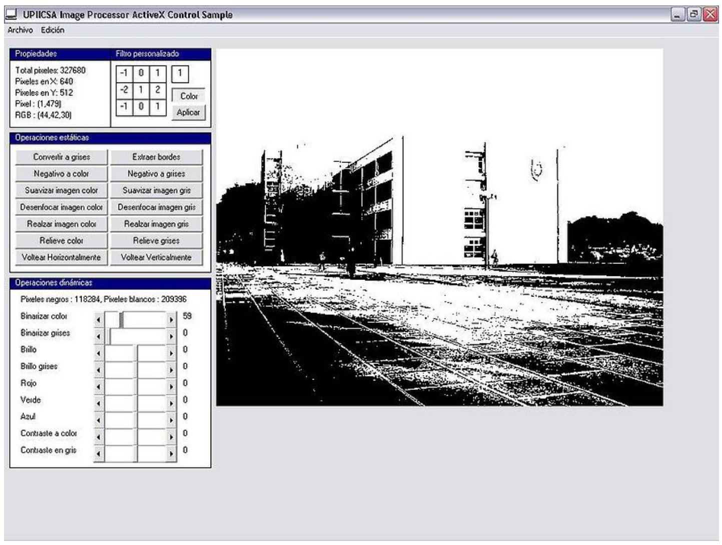
Image processing



Monochrome black/white image

In electrical engineering and computer science, **image processing** is any form of signal processing for which the input is an image, such as photographs or frames of video; the output of image processing can be either an image or a set of characteristics or parameters related to the image. Most image-processing techniques involve treating the image as a two-dimensional signal and applying standard signal-processing techniques to it.

Image processing usually refers to digital image processing, but optical and analog image processing are also possible. This article is about general techniques that apply to all of them. The *acquisition* of images (producing the input image in the first place) is referred to as imaging.

Typical operations

The red, green, and blue color channels of a photograph by Sergei Mikhailovich Prokudin-Gorskii. The fourth image is a composite.

Among many other image processing operations are:

- Euclidean geometry transformations such as enlargement, reduction, and rotation
- Color corrections such as brightness and contrast adjustments, color mapping, color balancing, quantization, or color translation to a different color space
- Digital compositing or optical compositing (combination of two or more images). Used in film-making to make a "matte"
- Interpolation, demosaicing, and recovery of a full image from a raw image format using a Bayer filter pattern
- Image registration, the alignment of two or more images
- Image differencing and morphing
- Image recognition, for example, extract the text from the image using optical character recognition or checkbox and bubble values using optical mark recognition
- Image segmentation
- High dynamic range imaging by combining multiple images
- Geometric hashing for 2-D object recognition with affine invariance

Applications

- Computer vision
- Optical sorting
- Augmented Reality
- Face detection
- Feature detection
- Lane departure warning system
- Non-photorealistic rendering
- Medical image processing
- Microscope image processing
- Morphological image processing
- Remote sensing

See also

- Imaging
- Photo manipulation
- List of image analysis software
- Near sets
- Multidimensional systems

Further reading

- Tinku Acharya and Ajoy K. Ray. *Image Processing - Principles and Applications* [1]. Wiley InterScience.
- Wilhelm Burger and Mark J. Burge (2007). *Digital Image Processing: An Algorithmic Approach Using Java* [2]. Springer. ISBN 1846283795 and ISBN 3540309403.
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External links

- Lectures on Image Processing [3], by Alan Peters. Vanderbilt University. Updated 28 April 2008.
- EURASIP Journal on Image and Video Processing [4] — Open Access journal on Image Processing
- Image processing algorithms, implementations and demonstrations [5]

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[4] http://www.hindawi.com/journals/ivp/
[5] http://www.ipol.im/

Digital image processing

Digital image processing is the use of computer algorithms to perform image processing on digital images. As a subfield of digital signal processing, digital image processing has many advantages over analog image processing; it allows a much wider range of algorithms to be applied to the input data, and can avoid problems such as the build-up of noise and signal distortion during processing. Since images are defined over two dimensions (perhaps more) digital image processing can be modeled in the form of Multidimensional Systems.

History

Many of the techniques of digital image processing, or digital picture processing as it was often called, were developed in the 1960s at the Jet Propulsion Laboratory, MIT, Bell Labs, University of Maryland, and a few other places, with application to satellite imagery, wirephoto standards conversion, medical imaging, videophone, character recognition, and photo enhancement.[1] But the cost of processing was fairly high with the computing equipment of that era. In the 1970s, digital image processing proliferated, when cheaper computers and dedicated hardware became available. Images could then be processed in real time, for some dedicated problems such as television standards conversion. As general-purpose computers became faster, they started to take over the role of dedicated hardware for all but the most specialized and compute-intensive operations.

With the fast computers and signal processors available in the 2000s, digital image processing has become the most common form of image processing, and is generally used because it is not only the most versatile method, but also the cheapest.

Digital image processing technology for medical applications was inducted into the Space Foundation Space Technology Hall of Fame in 1994.[2]

Tasks

Digital image processing allows the use of much more complex algorithms for image processing, and hence can offer both more sophisticated performance at simple tasks, and the implementation of methods which would be impossible by analog means.

In particular, digital image processing is the only practical technology for:

- Classification
- Feature extraction
- Pattern recognition
- Projection
- Multi-scale signal analysis

Some techniques which are used in digital image processing include:

- Pixelization
- Linear filtering
- Principal components analysis
- Independent component analysis
- Hidden Markov models
- Partial differential equations
- Self-organizing maps
- Neural networks
- Wavelets

Applications

Digital camera images

Digital cameras generally include dedicated digital image processing chips to convert the raw data from the image sensor into a color-corrected image in a standard image file format. Images from digital cameras often receive further processing to improve their quality, a distinct advantage digital cameras have over film cameras. The digital image processing is typically done by special software programs that can manipulate the images in many ways.

Many digital cameras also enable viewing of histograms of images, as an aid for the photographer to better understand the rendered brightness range of each shot.

Film

Westworld (1973) was the first feature film to use digital image processing to pixellate photography to simulate an android's point of view.[3]

See also

- Computer graphics
- Computer vision
- Digitizing
- Endrov
- GPGPU
- ImageJ

- FIJI (software)
- Homomorphic filtering
- OpenCV
- Standard test image
- Super-resolution
- Multidimensional systems

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External links

- Tutorial for image processing [4] (contains a Java applet)
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Optical character recognition

Optical character recognition, usually abbreviated to **OCR**, is the mechanical or electronic translation of scanned images of handwritten, typewritten or printed text into machine-encoded text. It is widely used to convert books and documents into electronic files, to computerize a record-keeping system in an office, or to publish the text on a website. OCR makes it possible to edit the text, search for a word or phrase, store it more compactly, display or print a copy free of scanning artifacts, and apply techniques such as machine translation, text-to-speech and text mining to it. OCR is a field of research in pattern recognition, artificial intelligence and computer vision.

OCR systems require calibration to read a specific font; early versions needed to be programmed with images of each character, and worked on one font at a time. "Intelligent" systems with a high degree of recognition accuracy for most fonts are now common. Some systems are capable of reproducing formatted output that closely approximates the original scanned page including images, columns and other non-textual components.

History

In 1929 Gustav Tauschek obtained a patent on OCR in Germany, followed by Handel who obtained a US patent on OCR in USA in 1933 (U.S. Patent 1,915,993 [1]). In 1935 Tauschek was also granted a US patent on his method (U.S. Patent 2,026,329 [2]). Tauschek's machine was a mechanical device that used templates and a photodetector.

In 1950, David H. Shepard, a cryptanalyst at the Armed Forces Security Agency in the United States, addressed the problem of converting printed messages into machine language for computer processing and built a machine to do this, reported in the Washington Daily News on 27 April 1951 and in the New York Times on 26 December 1953 after his U.S. Patent 2,663,758 [3] was issued. Shepard then founded Intelligent Machines Research Corporation (IMR), which went on to deliver the world's first several OCR systems used in commercial operation.

The first commercial system was installed at the Readers Digest in 1955. The second system was sold to the Standard Oil Company for reading credit card imprints for billing purposes. Other systems sold by IMR during the late 1950s included a bill stub reader to the Ohio Bell Telephone Company and a page scanner to the United States Air Force for reading and transmitting by teletype typewritten messages. IBM and others were later licensed on Shepard's OCR patents.

In about 1965 Readers Digest and RCA collaborated to build an OCR Document reader designed to digitize the serial numbers on Reader Digest coupons returned from advertisements. The font used on the documents were printed by an RCA Drum printer using the OCR-A font. The reader was connected directly to an RCA 301 computer (one of the first solid state computers). This reader was followed by a specialized document reader installed at TWA where the reader processed Airline Ticket stock. The readers processed document at a rate of 1,500 documents per minute, and checked each document, rejecting those it was not able to process correctly. The product became part of the RCA product line as a reader designed to process "Turn around Documents" such as those Utility and insurance bills returned with payments.

The United States Postal Service has been using OCR machines to sort mail since 1965 based on technology devised primarily by the prolific inventor Jacob Rabinow. The first use of OCR in Europe was by the British General Post Office (GPO). In 1965 it began planning an entire banking system, the National Giro, using OCR technology, a process that revolutionized bill payment systems in the UK. Canada Post has been using OCR systems since 1971. OCR systems read the name and address of the addressee at the first mechanized sorting center, and print a routing bar code on the envelope based on the postal code. To avoid confusion with the human-readable address field which can be located anywhere on the letter, special ink (orange in visible light) is used that is clearly visible under ultraviolet light. Envelopes may then be processed with equipment based on simple barcode readers.

In 1974 Ray Kurzweil started the company Kurzweil Computer Products, Inc. and led development of the first omni-font optical character recognition system — a computer program capable of recognizing text printed in any normal font. He decided that the best application of this technology would be to create a reading machine for the blind, which would allow blind people to have a computer read text to them out loud. This device required the invention of two enabling technologies — the CCD flatbed scanner and the text-to-speech synthesizer. On January 13, 1976 the successful finished product was unveiled during a widely-reported news conference headed by Kurzweil and the leaders of the National Federation of the Blind.

In 1978 Kurzweil Computer Products began selling a commercial version of the optical character recognition computer program. LexisNexis was one of the first customers, and bought the program to upload paper legal and news documents onto its nascent online databases. Two years later, Kurzweil sold his company to Xerox, which had an interest in further commercializing paper-to-computer text conversion. Kurzweil Computer Products became a subsidiary of Xerox known as Scansoft, now Nuance Communications.

Current state of OCR technology

The accurate recognition of Latin-script, typewritten text is now considered largely a solved problem on applications where clear imaging is available such as scanning of printed documents. Typical accuracy rates on these exceed 99%; total accuracy can only be achieved by human review. Other areas—including recognition of hand printing, cursive handwriting, and printed text in other scripts (especially those with a very large number of characters)—are still the subject of active research.

Accuracy rates can be measured in several ways, and how they are measured can greatly affect the reported accuracy rate. For example, if word context (basically a lexicon of words) is not used to correct software finding non-existent words, a character error rate of 1% (99% accuracy) may result in an error rate of 5% (95% accuracy) or worse if the measurement is based on whether each whole word was recognized with no incorrect letters[4] .

On-line character recognition is sometimes confused with Optical Character Recognition[5] (see Handwriting recognition). OCR is an instance of off-line character recognition, where the system recognizes the fixed *static shape* of the character, while on-line character recognition instead recognizes the *dynamic motion* during handwriting. For example, on-line recognition, such as that used for gestures in the Penpoint OS or the Tablet PC can tell whether a horizontal mark was drawn right-to-left, or left-to-right. On-line character recognition is also referred to by other terms such as dynamic character recognition, real-time character recognition, and Intelligent Character Recognition or ICR.

On-line systems for recognizing hand-printed text on the fly have become well-known as commercial products in recent years (see Tablet PC history). Among these are the input devices for personal digital assistants such as those running Palm OS. The Apple Newton pioneered this product. The algorithms used in these devices take advantage of the fact that the order, speed, and direction of individual lines segments at input are known. Also, the user can be retrained to use only specific letter shapes. These methods cannot be used in software that scans paper documents, so accurate recognition of hand-printed documents is still largely an open problem. Accuracy rates of 80% to 90% on neat, clean hand-printed characters can be achieved, but that accuracy rate still translates to dozens of errors per page, making the technology useful only in very limited applications.

Recognition of cursive text is an active area of research, with recognition rates even lower than that of hand-printed text. Higher rates of recognition of general cursive script will likely not be possible without the use of contextual or grammatical information. For example, recognizing entire words from a dictionary is easier than trying to parse individual characters from script. Reading the *Amount* line of a cheque (which is always a written-out number) is an example where using a smaller dictionary can increase recognition rates greatly. Knowledge of the grammar of the language being scanned can also help determine if a word is likely to be a verb or a noun, for example, allowing greater accuracy. The shapes of individual cursive characters themselves simply do not contain enough information to accurately (greater than 98%) recognize all handwritten cursive script.

It is necessary to understand that OCR technology is a basic technology also used in advanced scanning applications. Due to this, an advanced scanning solution can be unique and patented and not easily copied despite being based on this basic OCR technology.

For more complex recognition problems, intelligent character recognition systems are generally used, as artificial neural networks can be made indifferent to both affine and non-linear transformations.[6]

A technique which is having considerable success in recognising difficult words and character groups within documents generally amenable to computer OCR is to submit them automatically to humans in the reCAPTCHA system.

OCR software

OCR Software and ICR Software technology are analytical artificial intelligence systems that consider sequences of characters rather than whole words or phrases. Based on the analysis of sequential lines and curves, OCR and ICR make 'best guesses' at characters using database look-up tables to closely associate or match the strings of characters that form words.

See also

- Automatic number plate recognition
- CAPTCHA
- Computational linguistics
- Computer vision
- Digital Mailroom
- Machine learning
- Music OCR
- OCR SDK
- OCR Software
- Optical mark recognition
- Raster to vector
- Raymond Kurzweil
- Speech recognition
- Book scanning
- Institutional Repository
- Digital Library
- OCR-B

External links

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- Free Online OCR [9] Free Online OCR

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[8] http://www.unicode.org/charts/PDF/U2440.pdf
[9] http://www.free-online-ocr.com

Applications

Computer vision

Computer vision is the science and technology of machines that see. As a scientific discipline, computer vision is concerned with the theory behind artificial systems that extract information from images. The image data can take many forms, such as video sequences, views from multiple cameras, or multi-dimensional data from a medical scanner.

As a technological discipline, computer vision seeks to apply its theories and models to the construction of computer vision systems. Examples of applications of computer vision include systems for:

- Controlling processes (e.g., an industrial robot or an autonomous vehicle).
- Detecting events (e.g., for visual surveillance or people counting).
- Organizing information (e.g., for indexing databases of images and image sequences).
- Modeling objects or environments (e.g., industrial inspection, medical image analysis or topographical modeling).
- Interaction (e.g., as the input to a device for computer-human interaction).

Computer vision is closely related to the study of biological vision. The field of biological vision studies and models the physiological processes behind visual perception in humans and other animals. Computer vision, on the other hand, studies and describes the processes implemented in software and hardware behind artificial vision systems. Interdisciplinary exchange between biological and computer vision has proven fruitful for both fields.

Computer vision is, in some ways, the inverse of computer graphics. While computer graphics produces image data from 3D models, computer vision often produces 3D models from image data. There is also a trend towards a combination of the two disciplines, e.g., as explored in augmented reality.

Sub-domains of computer vision include scene reconstruction, event detection, video tracking, object recognition, learning, indexing, motion estimation, and image restoration.

State of the art

Computer vision is a diverse and relatively new field of study. In the early days of computing, it was difficult to process even moderately large sets of image data. It was not until the late 1970s that a more focused study of the field emerged. Computer vision covers a wide range of topics which are often related to other disciplines, and consequently there is no standard formulation of "the computer vision problem". Moreover, there is no standard formulation of how computer vision problems should be solved. Instead, there exists an abundance of methods for solving various well-defined computer vision tasks, where the methods often are very task specific and seldom can be generalized over a wide range of applications. Many of the methods and applications are still in the state of basic research, but more and more methods have found their way into commercial products, where they often constitute a part of a larger system which can solve complex tasks (e.g., in the area of medical images, or quality control and measurements in industrial processes). In most practical computer vision applications, the computers are pre-programmed to solve a particular task, but methods based on learning are now becoming increasingly common.

Related fields

Much of artificial intelligence deals with autonomous planning or deliberation for robotical systems to navigate through an environment. A detailed understanding of these environments is required to navigate through them. Information about the environment could be provided by a computer vision system, acting as a vision sensor and providing high-level information about the environment and the robot. Artificial intelligence and computer vision share other topics such as pattern recognition and learning techniques. Consequently, computer vision is sometimes seen as a part of the artificial intelligence field or the computer science field in general.

Physics is another field that is closely related to computer vision. Computer vision systems rely on image sensors which detect electromagnetic radiation which is typically in the form of either visible or infra-red light. The sensors are designed using solid-state physics. The process by which light propagates and reflects off surfaces is explained using optics. Sophisticated image sensors even require quantum mechanics to provide a complete understanding of the image formation process. Also, various measurement problems in physics can be addressed using computer vision, for example motion in fluids.

A third field which plays an important role is neurobiology, specifically the study of the biological vision system. Over the last century, there has been an extensive study of eyes, neurons, and the brain structures devoted to processing of visual stimuli in both humans and various animals. This has led to a coarse, yet complicated, description of how "real" vision systems operate in order to solve certain vision related tasks. These results have led to a subfield within computer vision where artificial systems are designed to mimic the processing and behavior of biological systems, at different levels of complexity. Also, some of the learning-based methods developed within computer vision have their background in biology.

Yet another field related to computer vision is signal processing. Many methods for processing of one-variable signals, typically temporal signals, can be extended in a natural way to processing of two-variable signals or multi-variable signals in computer vision. However, because of the specific nature of images there are many methods developed within computer vision which have no counterpart in the processing of one-variable signals. A distinct character of these methods is the fact that they are non-linear which, together with the multi-dimensionality of the signal, defines a subfield in signal processing as a part of computer vision.

Beside the above mentioned views on computer vision, many of the related research topics can also be studied from a purely mathematical point of view. For example, many methods in computer vision are based on statistics, optimization or geometry. Finally, a significant part of the field is devoted to the implementation aspect of computer vision; how existing methods can be realized in various combinations of software and hardware, or how these methods can be modified in order to gain processing speed without losing too much performance.

The fields most closely related to computer vision are image processing, image analysis and machine vision. There is a significant overlap in the range of techniques and applications that these cover. This implies that the basic techniques that are used and developed in these fields are more or less identical, something which can be interpreted as there is only one field with different names. On the other hand, it appears to be necessary for research groups, scientific journals, conferences and companies to present or market themselves as belonging specifically to one of these fields and, hence, various characterizations which distinguish each of the fields from the others have been presented.

The following characterizations appear relevant but should not be taken as universally accepted:

- Image processing and image analysis tend to focus on 2D images, how to transform one image to another, e.g., by pixel-wise operations such as contrast enhancement, local operations such as edge extraction or noise removal, or geometrical transformations such as rotating the image. This characterization implies that image processing/analysis neither require assumptions nor produce interpretations about the image content.
- Computer vision tends to focus on the 3D scene projected onto one or several images, e.g., how to reconstruct structure or other information about the 3D scene from one or several images. Computer vision often relies on

more or less complex assumptions about the scene depicted in an image.

- Machine vision tends to focus on applications, mainly in manufacturing, e.g., vision based autonomous robots and systems for vision based inspection or measurement. This implies that image sensor technologies and control theory often are integrated with the processing of image data to control a robot and that real-time processing is emphasized by means of efficient implementations in hardware and software. It also implies that the external conditions such as lighting can be and are often more controlled in machine vision than they are in general computer vision, which can enable the use of different algorithms.
- There is also a field called imaging which primarily focus on the process of producing images, but sometimes also deals with processing and analysis of images. For example, medical imaging contains lots of work on the analysis of image data in medical applications.
- Finally, pattern recognition is a field which uses various methods to extract information from signals in general, mainly based on statistical approaches. A significant part of this field is devoted to applying these methods to image data.

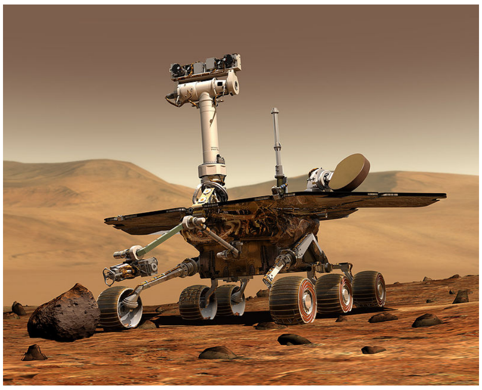
Applications for computer vision

One of the most prominent application fields is medical computer vision or medical image processing. This area is characterized by the extraction of information from image data for the purpose of making a medical diagnosis of a patient. Generally, image data is in the form of microscopy images, X-ray images, angiography images, ultrasonic images, and tomography images. An example of information which can be extracted from such image data is detection of tumours, arteriosclerosis or other malign changes. It can also be measurements of organ dimensions, blood flow, etc. This application area also supports medical research by providing new information, e.g., about the structure of the brain, or about the quality of medical treatments.

A second application area in computer vision is in industry, sometimes called machine vision, where information is extracted for the purpose of supporting a manufacturing process. One example is quality control where details or final products are being automatically inspected in order to find defects. Another example is measurement of position and orientation of details to be picked up by a robot arm. Machine vision is also heavily used in agricultural process to remove undesirable food stuff from bulk material, a process called optical sorting.

Military applications are probably one of the largest areas for computer vision. The obvious examples are detection of enemy soldiers or vehicles and missile guidance. More advanced systems for missile guidance send the missile to an area rather than a specific target, and target selection is made when the missile reaches the area based on locally acquired image data. Modern military concepts, such as "battlefield awareness", imply that various sensors, including image sensors, provide a rich set of information about a combat scene which can be used to support strategic decisions. In this case, automatic processing of the data is used to reduce complexity and to fuse information from multiple sensors to increase reliability.

One of the newer application areas is autonomous vehicles, which include submersibles, land-based vehicles (small robots with wheels, cars or trucks), aerial vehicles, and unmanned aerial vehicles (UAV). The level of autonomy ranges from fully autonomous (unmanned) vehicles to vehicles where computer vision based systems support a driver or a pilot in various situations. Fully autonomous vehicles typically use computer vision for navigation, i.e. for knowing where it is, or for producing a map of its environment (SLAM) and for detecting obstacles. It can also be used for detecting certain task specific events, e. g., a UAV looking for forest fires. Examples of supporting systems are obstacle warning systems in cars, and systems for autonomous landing of aircraft. Several car manufacturers have demonstrated systems for autonomous driving of cars, but this technology has still not reached a level where it can be put on the market. There are ample examples of military autonomous vehicles ranging from advanced missiles, to UAVs for recon missions or missile guidance. Space exploration is already being made with autonomous vehicles using computer vision, e. g., NASA's Mars Exploration Rover and ESA's ExoMars Rover.



Artist's Concept of Rover on Mars, an example of an unmanned land-based vehicle. Notice the stereo cameras mounted on top of the Rover. (credit: Maas Digital LLC)

Other application areas include:

- Support of visual effects creation for cinema and broadcast, e.g., camera tracking (matchmoving).
- Surveillance.

Typical tasks of computer vision

Each of the application areas described above employ a range of computer vision tasks; more or less well-defined measurement problems or processing problems, which can be solved using a variety of methods. Some examples of typical computer vision tasks are presented below.

Recognition

The classical problem in computer vision, image processing, and machine vision is that of determining whether or not the image data contains some specific object, feature, or activity. This task can normally be solved robustly and without effort by a human, but is still not satisfactorily solved in computer vision for the general case: arbitrary objects in arbitrary situations. The existing methods for dealing with this problem can at best solve it only for specific objects, such as simple geometric objects (e.g., polyhedra), human faces, printed or hand-written characters, or vehicles, and in specific situations, typically described in terms of well-defined illumination, background, and pose of the object relative to the camera.

Different varieties of the recognition problem are described in the literature:

- **Object recognition**: one or several pre-specified or learned objects or object classes can be recognized, usually together with their 2D positions in the image or 3D poses in the scene.
- **Identification**: An individual instance of an object is recognized. Examples: identification of a specific person's face or fingerprint, or identification of a specific vehicle.
- **Detection**: the image data is scanned for a specific condition. Examples: detection of possible abnormal cells or tissues in medical images or detection of a vehicle in an automatic road toll system. Detection based on relatively simple and fast computations is sometimes used for finding smaller regions of interesting image data which can be further analyzed by more computationally demanding techniques to produce a correct interpretation.

Several specialized tasks based on recognition exist, such as:

- **Content-based image retrieval**: finding all images in a larger set of images which have a specific content. The content can be specified in different ways, for example in terms of similarity relative a target image (give me all images similar to image X), or in terms of high-level search criteria given as text input (give me all images which contains many houses, are taken during winter, and have no cars in them).
- **Pose estimation**: estimating the position or orientation of a specific object relative to the camera. An example application for this technique would be assisting a robot arm in retrieving objects from a conveyor belt in an assembly line situation.
- **Optical character recognition** (OCR): identifying characters in images of printed or handwritten text, usually with a view to encoding the text in a format more amenable to editing or indexing (e.g. ASCII).

Motion analysis

Several tasks relate to motion estimation where an image sequence is processed to produce an estimate of the velocity either at each points in the image or in the 3D scene, or even of the camera that produces the images . Examples of such tasks are:

- **Egomotion**: determining the 3D rigid motion (rotation and translation) of the camera from an image sequence produced by the camera.
- **Tracking**: following the movements of a (usually) smaller set of interest points or objects (e.g., vehicles or humans) in the image sequence.
- **Optical flow**: to determine, for each point in the image, how that point is moving relative to the image plane, i.e., its apparent motion. This motion is a result both of how the corresponding 3D point is moving in the scene and how the camera is moving relative to the scene.

Scene reconstruction

Given one or (typically) more images of a scene, or a video, scene reconstruction aims at computing a 3D model of the scene. In the simplest case the model can be a set of 3D points. More sophisticated methods produce a complete 3D surface model.

Image restoration

The aim of image restoration is the removal of noise (sensor noise, motion blur, etc.) from images. The simplest possible approach for noise removal is various types of filters such as low-pass filters or median filters. More sophisticated methods assume a model of how the local image structures look like, a model which distinguishes them from the noise. By first analysing the image data in terms of the local image structures, such as lines or edges, and then controlling the filtering based on local information from the analysis step, a better level of noise removal is usually obtained compared to the simpler approaches.

Computer vision systems

The organization of a computer vision system is highly application dependent. Some systems are stand-alone applications which solve a specific measurement or detection problem, while others constitute a sub-system of a larger design which, for example, also contains sub-systems for control of mechanical actuators, planning, information databases, man-machine interfaces, etc. The specific implementation of a computer vision system also depends on if its functionality is pre-specified or if some part of it can be learned or modified during operation. There are, however, typical functions which are found in many computer vision systems.

- **Image acquisition**: A digital image is produced by one or several image sensors, which, besides various types of light-sensitive cameras, include range sensors, tomography devices, radar, ultra-sonic cameras, etc. Depending on the type of sensor, the resulting image data is an ordinary 2D image, a 3D volume, or an image sequence. The pixel values typically correspond to light intensity in one or several spectral bands (gray images or colour images), but can also be related to various physical measures, such as depth, absorption or reflectance of sonic or electromagnetic waves, or nuclear magnetic resonance.

- **Pre-processing**: Before a computer vision method can be applied to image data in order to extract some specific piece of information, it is usually necessary to process the data in order to assure that it satisfies certain assumptions implied by the method. Examples are
  - Re-sampling in order to assure that the image coordinate system is correct.
  - Noise reduction in order to assure that sensor noise does not introduce false information.
  - Contrast enhancement to assure that relevant information can be detected.
  - Scale-space representation to enhance image structures at locally appropriate scales.
- **Feature extraction**: Image features at various levels of complexity are extracted from the image data. Typical examples of such features are
  - Lines, edges and ridges.
  - Localized interest points such as corners, blobs or points.

  More complex features may be related to texture, shape or motion.
- **Detection/segmentation**: At some point in the processing a decision is made about which image points or regions of the image are relevant for further processing. Examples are
  - Selection of a specific set of interest points
  - Segmentation of one or multiple image regions which contain a specific object of interest.
- **High-level processing**: At this step the input is typically a small set of data, for example a set of points or an image region which is assumed to contain a specific object. The remaining processing deals with, for example:
  - Verification that the data satisfy model-based and application specific assumptions.
  - Estimation of application specific parameters, such as object pose or object size.
  - Classifying a detected object into different categories.

See also

- Active vision
- Artificial intelligence, Strong AI
- Digital image processing
- Image processing
- List of computer vision topics
- Machine learning
- Machine vision
- Machine vision glossary
- Medical imaging
- Pattern recognition
- Photogrammetry

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External links

General resources

- Keith Price's Annotated Computer Vision Bibliography [6] and the Official Mirror Site Keith Price's Annotated Computer Vision Bibliography [7]
- USC Iris computer vision conference list [8]
- Computer Vision Online [9]
- Computer Vision Central [10]
- The Computer Vision Genealogy Project [11]

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[2] http://www.nada.kth.se/~tony/book.html
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[4] http://www.mas.ecp.fr/vision/Personnel/nikos/paragios-chen-faugeras/
[5] http://ivt.sourceforge.net/book.html
[6] http://iris.usc.edu/Vision-Notes/bibliography/contents.html
[7] http://www.visionbib.com/bibliography/contents.html
[8] http://iris.usc.edu/Information/Iris-Conferences.html
[9] http://www.ComputerVisionOnline.com
[10] http://www.ComputerVisionCentral.com
[11] http://visiongenealogy.summerhost.info/

Optical sorting

Optical Sorting is a process of visually sorting a product though the use of Photodetector (light sensors), Camera[1] , or the standard Mark 1 Human eye ball[2] .

In its simplest operation, a machine will simply see how much light is reflected off the object using a simple Photodetector (such as a Photoresistor) and accept or reject the item depending of how reflective it is (light or dark).

More sophisticated systems use Image processing to discriminate the colors of the object, often via a controlled spectra of light, even beyond the visible spectrum into the IR and UV range. Shape detection is an evolving ability.

The common method of removal is jets of compressed air, but other exist.

The term "Optical sorting" also includes manual seeing and manipulating process.

Satake Corporation, Best [3], and Sortex [4] are three of several companies that build Optical Sorting machines.

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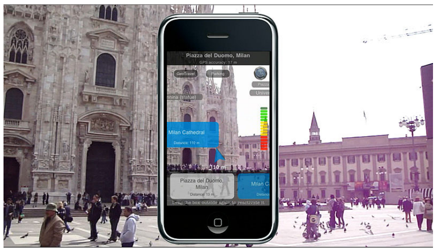
[2] "Image Processing for the Food Industry", E. R. Davis; World Scientific Publishing Co. Pte. Ltd.; London, 2000
[3] http://www.bestnv.com/
[4] http://www.buhlergroup.com/17217EN.asp

Augmented Reality

Augmented reality (AR) is a term for a live direct or indirect view of a physical real-world environment whose elements are *augmented* by virtual computer-generated imagery. It is related to a more general concept called mediated reality in which a view of reality is modified (possibly even diminished rather than augmented) by a computer. As a result, the technology functions by enhancing one’s current perception of reality.



Augmented GeoTravel for the iPhone 3GS uses the compass, the GPS and the accelerometers to show the Augmented Reality view

In the case of Augmented Reality, the augmentation is conventionally in real-time and in semantic context with environmental elements, such as sports scores on TV during a match. With the help of advanced AR technology (e.g. adding computer vision and object recognition) the information about the surrounding real world of the user becomes interactive and digitally usable. Artificial information about the environment and the objects in it can be stored and retrieved as an information layer on top of the real world view. The term augmented reality is believed to have been coined in 1990 by Thomas Caudell, an employee of Boeing at the time[1] .

Wikitude World Browser on the iPhone 3GS uses GPS and solid state compass

Augmented reality research explores the application of computer-generated imagery in live-video streams as a way to expand the real-world. Advanced research includes use of head-mounted displays and virtual retinal displays for visualization purposes, and construction of controlled environments containing any number of sensors and actuators.

AR Tower Defense game on the Nokia N95 smartphone (Symbian OS) uses fiduciary markers

Definition

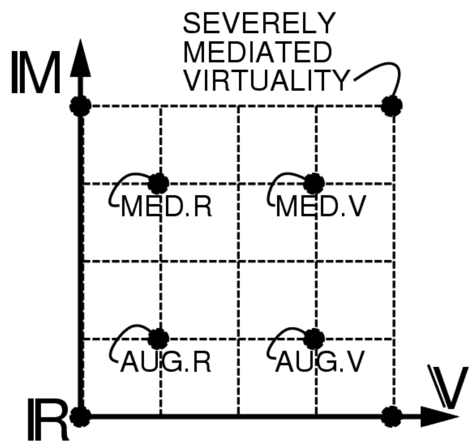
There are two commonly accepted definitions of Augmented Reality today. One was given by Ronald Azuma in 1997 [2] . **Azuma's definition** says that Augmented Reality

- combines real and virtual
- is interactive in real time
- is registered in 3D

Additionally Paul Milgram and Fumio Kishino defined **Milgram's Reality-Virtuality Continuum** in 1994 [3] . They describe a continuum that spans from the real environment to a pure virtual environment. In between there are Augmented Reality (closer to the real environment) and Augmented Virtuality (is closer to the virtual environment).

Milgram's Continuum

This continuum has been extended into a two-dimensional plane of "Virtuality" and "Mediality"[4] . Taxonomy of Reality, Virtuality, Mediality. The origin R denotes unmodified reality. A continuum across the Virtuality axis V includes reality augmented with graphics (Augmented Reality), as well as graphics augmented by reality (Augmented Virtuality). However, the taxonomy also includes modification of reality or virtuality or any combination of these. The modification is denoted by moving up the mediality axis. Further up this axis, for example, we can find mediated reality, mediated virtuality, or any combination of these. Further up and to the right we have virtual worlds that are responsive to a severely modified version of reality. (at right) Mediated reality generalizes the concepts of mixed reality, etc.. It includes the virtuality reality continuum (mixing) but also, in addition to additive effects, also includes multiplicatave effects (modulation) of (sometimes deliberately) diminished reality. Moreover, it considers, more generally, that reality may be modified in various ways. The mediated reality framework describes devices that deliberately modify reality, as well as devices that accidentally modify it.



Mediated Reality continuum showing four points: Augmented Reality, Augmented Virtuality, Mediated Reality, and Mediated Virtuality on the Virtuality and Mediality axes

More recently, the term augmented reality has been blurred a bit due to the increased interest of the general public in AR.

Examples

Commonly known examples of AR are the yellow "first down" lines seen in television broadcasts of American football games using the 1st & Ten system, and the colored trail showing location and direction of the puck in TV broadcasts of ice hockey games. The real-world elements are the football field and players, and the virtual element is the yellow line, which is drawn over the image by computers in real time. Similarly, rugby fields and cricket pitches are branded by their sponsors using Augmented Reality; giant logos are inserted onto the fields when viewed on television. In some cases, the modification of reality goes beyond mere augmentation. For example, advertisements may be blocked out (partially or wholly *diminished*) and replaced with different advertisements. Such replacement is an example of Mediated reality, a more general concept than AR.

Television telecasts of swimming events also often have a virtual line which indicates the position of the current world record holder at that time.

Another type of AR application uses projectors and screens to insert objects into the real environment, enhancing museum exhibitions for example. The difference to a simple TV screen for example, is that these objects are related to the environment of the screen or display, and that they often are interactive as well.

Many first-person shooter video games simulate the viewpoint of someone using AR systems. In these games the AR can be used to give visual directions to a location, mark the direction and distance of another person who is not in line of sight, give information about equipment such as remaining bullets in a gun, and display a myriad of other images based on whatever the game designers intend. This is also called the head-up display.

In some current applications like in cars or airplanes, this is usually a head-up display integrated into the windshield.

The F-35 Lightning II has no Head-up display. This is because all targets are tracked by the aircraft's situational awareness and the sensor fusion is presented in the pilot's helmet mounted display. The helmet mounted display provides an augmented reality system that allows the pilot to look through his own aircraft as if it wasn't there.

History

- 1957-62: Morton Heilig, a cinematographer, creates and patents a simulator called Sensorama with visuals, sound, vibration, and smell.[5]
- 1966: Ivan Sutherland invents the head-mounted display suggesting it was a window into a virtual world.
- 1975: Myron Krueger creates Videoplace that allows users to interact with virtual objects for the first time.
- 1989: Jaron Lanier coins the phrase Virtual Reality and creates the first commercial business around virtual worlds.
- 1992: Tom Caudell [6] coins the phrase **Augmented Reality** while at Boeing helping workers assemble cables into aircraft.
- 1992: L.B. Rosenberg develops one of the first functioning AR systems, called VIRTUAL FIXTURES, at the U.S. Air Force Armstrong Labs, and demonstrates benefit on human performance.[7] [8]
- 1992: Steven Feiner, Blair MacIntyre and Doree Seligmann present first major paper on an AR system prototype, KARMA, at the Graphics Interface conference. Widely cited version of the paper is published in Communications of the ACM next year.
- 1999: Hirokazu Kato (加藤 博一) develops ARToolKit at the HITLab and it is demonstrated at SIGGRAPH that year.
- 2000: Bruce H. Thomas develops ARQuake, the first outdoor mobile AR game, and is demonstrated in the International Symposium on Wearable Computers.
- 2008: Wikitude AR Travel Guide [9] launches on Oct. 20, 2008 with the G1 Android phone.
- 2009: Wikitude Drive - AR Navigation System launches on Oct. 28, 2009 for the Android platform.
- 2009: AR Toolkit is ported to Adobe Flash (FLARToolkit) by Saqoosha [10], bringing augmented reality to the web browser.
- 2010: acrossair [11], AR Browser bringing augmented reality to the mobile user on the iPhone 3Gs for hyper-local search.

Technology

Hardware

The main hardware components for augmented reality are: display, tracking, input devices, and computer. Combination of powerful CPU, camera, accelerometers, GPS and solid state compass are often present in modern smartphones, which make them prospective platforms for augmented reality.

Display

There are three major display techniques for Augmented Reality:

I. Head Mounted Displays
II. Handheld Displays
III. Spatial Displays

Head Mounted Displays

A Head Mounted Display (HMD) places images of both the physical world and registered virtual graphical objects over the user's view of the world. The HMD's are either optical see-through or video see-through in nature. An optical see-through display employs half-silver mirror technology to allow views of physical world to pass through the lens and graphical overlay information to be reflected into the user's eyes. The HMD must be tracked with a six degree of freedom sensor.This tracking allows for the computing system to register the virtual information to the physical world. The main advantage of HMD AR is the immersive experience for the user. The graphical information is slaved to the view of the user. The most common products employed are as follows: MicroVision

Nomad, Sony Glasstron, and I/O Displays.

Handheld Displays

Handheld Augment Reality employs a small computing device with a display that fits in a user's hand. All handheld AR solutions to date have employed video see-through techniques to overlay the graphical information to the physical world. Initially handheld AR employed sensors such as digital compasses and GPS units for its six degree of freedom tracking sensors. This moved onto the use of fiducial marker systems such as the ARToolKit for tracking. Today vision systems such as SLAM or PTAM are being employed for tracking. Handheld display AR promises to be the first commercial success for AR technologies. The two main advantages of handheld AR is the portable nature of handheld devices and ubiquitous nature of camera phones.

Spatial Displays

Instead of the user wearing or carrying the display such as with head mounted displays or handheld devices; Spatial Augmented Reality (SAR) makes use of digital projectors to display graphical information onto physical objects. The key difference in SAR is that the display is separated from the users of the system. Because the displays are not associated with each user, SAR scales naturally up to groups of users, thus allowing for collocated collaboration between users. SAR has several advantages over traditional head mounted displays and handheld devices. The user is not required to carry equipment or wear the display over their eyes. This makes spatial AR a good candidate for collaborative work, as the users can see each other’s faces. A system can be used by multiple people at the same time without each having to wear a head mounted display. Spatial AR does not suffer from the limited display resolution of current head mounted displays and portable devices. A projector based display system can simply incorporate more projectors to expand the display area. Where portable devices have a small window into the world for drawing, a SAR system can display on any number of surfaces of an indoor setting at once. The tangible nature of SAR makes this an ideal technology to support design, as SAR supports both a graphical visualisation and passive haptic sensation for the end users. People are able to touch physical objects, and it is this process that provides the passive haptic sensation. [2] [12] [13] [14]

Tracking

Modern mobile augmented reality systems use one or more of the following tracking technologies: digital cameras and/or other optical sensors, accelerometers, GPS, gyroscopes, solid state compasses, RFID, wireless sensors. Each of these technologies have different levels of accuracy and precision. Most important is the tracking of the pose and position of the user's head for the augmentation of the user's view. The user's hand(s) can tracked or a handheld input device could be tracked to provide a 6DOF interaction technique. Stationary systems can employ 6DOF track systems such as Polhemus, ViCON, A.R.T, or Ascension.

Input devices

This is a current open research question. Some systems, such as the Tinmith system, employ pinch glove techniques. Another common technique is a wand with a button on it. In case of smartphone, phone itself could be used as 3D pointing device, with 3D position of the phone restored from the camera images.

Computer

Camera based systems require powerful CPU and considerable amount of RAM for processing camera images. Wearable computing systems employ a laptop in a backpack configuration. For stationary systems a traditional workstation with a powerful graphics card. Sound processing hardware could be included in augmented reality systems.

Software

For consistent merging real-world images from camera and virtual 3D images, virtual images should be attached to real-world locations in visually realistic way. That means a real world coordinate system, independent from the camera, should be restored from camera images. That process is called Image registration and is part of Azuma's definition of Augmented Reality.

Augmented reality image registration uses different methods of computer vision, mostly related to video tracking. Many computer vision methods of augmented reality are inherited form similar visual odometry methods.

Usually those methods consist of two parts. First interest points, or fiduciary markers, or optical flow detected in the camera images. First stage can use Feature detection methods like Corner detection, Blob detection, Edge detection or thresholding and/or other image processing methods.

In the second stage, a real world coordinate system is restored from the data obtained in the first stage. Some methods assume objects with known 3D geometry(or fiduciary markers) present in the scene and make use of those data. In some of those cases all of the scene 3D structure should be precalculated beforehand. If not all of the scene is known beforehand SLAM technique could be used for mapping fiduciary markers/3D models relative positions. If no assumption about 3D geometry of the scene made structure from motion methods are used. Methods used in the second stage include projective(epipolar) geometry, bundle adjustment, rotation representation with exponential map, kalman and particle filters.

Applications

Current applications

Advertising: Marketers started to use AR to promote products via interactive AR applications. For example, at the 2008 LA Auto Show, Nissan unveiled the concept vehicle Cube and presented visitors with a brochure which, when held against a webcam, showed several versions of the vehicle[15] . In August 2009, Best Buy ran a circular with an augmented reality code that allowed users with a webcam to interact with the product in 3D.[16]

Support with complex tasks: Complex tasks such as assembly, maintenance, and surgery can be simplified by inserting additional information into the field of view. For example, labels can be displayed on parts of a system to clarify operating instructions for a mechanic who is performing maintenance on the system. [17] .AR can include images of hidden objects, which can be particularly effective for medical diagnostics or surgery. Examples include a virtual X-ray view based on prior tomography or on real time images from ultrasound or open NMR devices. A doctor could observe the fetus inside the mother's womb [18] .See also Mixed reality.

Navigation devices: AR can augment the effectiveness of navigation devices for a variety of applications. For example, building navigation can be enhanced for the purpose of maintaining industrial plants. Outdoor navigation can be augmented for military operations or disaster management. Head-up displays or personal display glasses in automobiles can be used to provide navigation hints and traffic information. These types of displays can be useful for airplane pilots, too. Head-up displays are currently used in fighter jets as one of the first AR applications. These include full interactivity, including eye pointing.

Industrial Applications: AR can be used to compare the data of digital mock-ups with physical mock-ups for efficiently finding discrepancys between the two sources. It can further be employed to safeguard digital data in combination with existing real prototypes, and thus save or minimize the building of real prototypes and improve the quality of the final product.

Military and emergency services: AR can be applied to military and emergency services as wearable systems to provide information such as instructions, maps, enemy locations, and fire cells.

Prospecting: In the fields of hydrology, ecology, and geology, AR can be used to display an interactive analysis of terrain characteristics. Users could use, and collaboratively modify and analyze, interactive three-dimensional maps.

Art: AR can be incorporated into artistic applications that allow artists to create art in real time over reality such as painting, drawing, modeling, etc. One such example of this phenomenon is called Eyewriter that was developed in 2009 by Zachary Lieberman and a group formed by members of Free Art and Technology (FAT), OpenFrameworks and the Graffiti Research Lab to help a graffiti artist, who became paralyzed, draw again. [19]

Architecture: AR can be employed to simulate planned construction projects.[20]

Sightseeing: Models may be created to include labels or text related to the objects/places visited. With AR, users can rebuild ruins, buildings, or even landscapes as they previously existed.[21]

Collaboration: AR can help facilitate collaboration among distributed team members via conferences with real and virtual participants. The Hand of God is a good example of a collaboration system [22] Also see Mixed reality.

Entertainment and education: AR can be used in the fields of entertainment and education to create virtual objects in museums and exhibitions, theme park attractions (such as Cadbury World), and games (such as ARQuake and The Eye of Judgment). Also see Mixed reality.

Music: Pop group Duran Duran included interactive AR projections into their stage show during their 2000 *Pop Trash* concert tour.[23] Sydney band Lost Valentinos launched the world's first interactive AR music video on 16 October 2009, where users could print out 5 markers representing a pre-recorded performance from each band member which they could interact with live and in real-time via their computer webcam and record as their own unique music video clips to share via YouTube.[24] [25]

Future applications

It is important to note that augmented reality is a costly development in technology. Because of this, the future of AR is dependent on whether or not those costs can be reduced in some way. If AR technology becomes affordable, it could be very widespread but for now major industries are the sole buyers that have the opportunity to utilize this resource.

- Expanding a PC screen into the real environment: program windows and icons appear as virtual devices in real space and are eye or gesture operated, by gazing or pointing. A single personal display (glasses) could concurrently simulate a hundred conventional PC screens or application windows all around a user
- Virtual devices of all kinds, e.g. replacement of traditional screens, control panels, and entirely new applications impossible in "real" hardware, like 3D objects interactively changing their shape and appearance based on the current task or need.
- Enhanced media applications, like pseudo holographic virtual screens, virtual surround cinema, virtual 'holodecks' (allowing computer-generated imagery to interact with live entertainers and audience)
- Virtual conferences in "holodeck" style
- Replacement of cellphone and car navigator screens: eye-dialing, insertion of information directly into the environment, e.g. guiding lines directly on the road, as well as enhancements like "X-ray"-views
- Virtual plants, wallpapers, panoramic views, artwork, decorations, illumination etc., enhancing everyday life. For example, a virtual window could be displayed on a regular wall showing a live feed of a camera placed on the exterior of the building, thus allowing the user to effectually toggle a wall's transparency
- With AR systems getting into mass market, we may see virtual window dressings, posters, traffic signs, Christmas decorations, advertisement towers and more. These may be fully interactive even at a distance, by eye pointing for example.
- Virtual gadgetry becomes possible. Any physical device currently produced to assist in data-oriented tasks (such as the clock, radio, PC, arrival/departure board at an airport, stock ticker, PDA, PMP, informational posters/fliers/billboards, in-car navigation systems, etc.) could be replaced by virtual devices that cost nothing to produce aside from the cost of writing the software. Examples might be a virtual wall clock, a to-do list for the day docked by your bed for you to look at first thing in the morning, etc.

- Subscribable group-specific AR feeds. For example, a manager on a construction site could create and dock instructions including diagrams in specific locations on the site. The workers could refer to this feed of AR items as they work. Another example could be patrons at a public event subscribing to a feed of direction and information oriented AR items.
- AR systems can help the visually impaired navigate in a much better manner (combined with a text-to-speech software).

Notable researchers

- Steven Feiner, Professor at Columbia University, is a leading pioneer of augmented reality, and author of the first paper on an AR system prototype, KARMA (the Knowledge-based Augmented Reality Maintenance Assistant), along with Blair MacIntyre and Doree Seligmann.[26]
- L.B. Rosenberg developed one of the first known AR systems, called Virtual Fixtures, while working at the U.S. Air Force Armstrong Labs in 1991, and published first study of how an AR system can enhance human performance.[7] [8]
- Mark Billinghurst and Daniel Wagner jump started the field of AR on mobile phones. They developed the first marker tracking systems for mobile phones and PDAs.[27]
- Bruce H. Thomas and Wayne Piekarski develop the Tinmith system in 1998. They along with Steve Feiner with his MARS system pioneer outdoor augmented reality.

Conferences

- 1st International Workshop on Augmented Reality, IWAR'98, San Francisco, Nov. 1998.
- 2nd International Workshop on Augmented Reality (IWAR'99 [28]), San Francisco, Oct. 1999.
- 1st International Symposium on Mixed Reality (ISMR'99), Yokohama, Japan, March 1999.
- 2nd International Symposium on Mixed Reality (ISMR'01), Yokohama, Japan, March 2001.
- 1st International Symposium on Augmented Reality (ISAR 2000 [29]), Munich, Oct. 2000.
- 2nd International Symposium on Augmented Reality (ISAR 2001 [30]), New York, Oct. 2001.
- 1st International Symposium on Mixed and Augmented Reality (ISMAR 2002 [31]), Darmstadt, Oct. 2002.
- 2nd International Symposium on Mixed and Augmented Reality (ISMAR 2003 [32]), Tokyo, Oct. 2003.
- 3rd International Symposium on Mixed and Augmented Reality (ISMAR 2004 [33]), Arlington, VA, Nov. 2004.
- 4th International Symposium on Mixed and Augmented Reality (ISMAR 2005 [34]), Vienna, Oct. 2005.
- 5th International Symposium on Mixed and Augmented Reality (ISMAR 2006 [35]) Santa Barbara, Oct. 2006.
- 6th International Symposium on Mixed and Augmented Reality (ISMAR 2007 [36]) Nara, Japan, Nov. 2007.
- 7th International Symposium on Mixed and Augmented Reality (ISMAR 2008 [37]) Cambridge, United Kingdom, Sep. 2008.
- 8th International Symposium on Mixed and Augmented Reality (ISMAR 2009 [38]) Orlando, Oct. 2009.
- Augmented Reality Developer Camp (AR DevCamp [39]) in Mountain View, Dec. 2009.

Software

Free software

- ARToolKit is a Cross-platform Library for the creation of augmented reality applications, developed by Hirokazu Kato in 1999 [40] and was released by the University of Washington HIT Lab. Currently it is maintained as an opensource project hosted on SourceForge [41] with commercial licenses available from ARToolWorks[42] .
- ATOMIC Authoring Tool is a Cross-platform Authoring Tool software, for Augmented Reality Applications, which is a Front end for the ARToolKit library. Was developed for non-programmers, to create small and simple, Augmented Reality applications, released under the GNU GPL License.
- ATOMIC Web Authoring Tool Is a children project from: ATOMIC Authoring Tool that enables the creation of Augmented Reality applications and export it, to any website. Developed as A front end (Graphic Interface) for the Flartoolkit library. And it's licensed under the GNU GPL License.
- *OSGART* [43] - a combination of ARToolKit and OpenSceneGraph
- *ARToolKitPlus* [44] - extended version of ARToolKit, only targeted to handheld users and developers of AR-oriented software. No longer developed.
- Mixed Reality Toolkit (MRT) [45] - University College London
- *FLARToolKit* [46] - an ActionScript 3 port of ARToolKit for Flash 9+.
- *SLARToolkit* [47] - a Silverlight port of NyARToolkit.
- *NyARToolkit* [48] - an ARToolkit class library released for virtual machines, particularly those which host Java, C# and Android.
- *ARDesktop* [49] - ARToolKit class library that creates a three-dimensional desktop interface with controls and widgets.
- *AndAR* [50] - A native port of ARToolkit to the Android platform.
- *mixare* [51] - Open-Source (GPLv3) Augmented Reality Engine for Android. It works as a completely autonomous application and is available as well for the development of own implementations.
- *OpenMAR* [52] - Open Mobile Augmented Reality component framework for the Symbian platform, released under EPL

Non-commercial use

- PTAM [53]
- ARTag [54]

Books

- Woodrow Barfield, and Thomas Caudell, eds. *Fundamentals of Wearable Computers and Augmented Reality.* Mahwah, NJ: Lawrence Erlbaum, 2001. ISBN 0805829016.
- Oliver Bimber and Ramesh Raskar. *Spatial Augmented Reality: Merging Real and Virtual Worlds*. A K Peters, 2005. ISBN 1568812302.
- Michael Haller, Mark Billinghurst and Bruce H. Thomas. *Emerging Technologies of Augmented Reality: Interfaces and Design.* Idea Group Publishing, 2006. ISBN 1599040662 , publisher listing [55]
- Rolf R. Hainich. *"The end of Hardware : A Novel Approach to Augmented Reality"* [56] 2nd ed.: Booksurge, 2006. ISBN 1419652184. 3rd ed. ("Augmented Reality and Beyond"): Booksurge, 2009, ISBN 1-4392-3602-X.
- Stephen Cawood and Mark Fiala. *Augmented Reality: A Practical Guide*, 2008, ISBN 1934356034

In popular culture

Television & film

- The television series *Dennō Coil* depicts a near-future where children use AR glasses to enhance their environment with games and virtual pets.
- The television series *Firefly* depicts numerous AR applications, including a real-time medical scanner which allows a doctor to use his hands to manipulate a detailed and labeled projection of a patient's brain.
- In the 1993 ABC miniseries Wild Palms, a Scientology-like organization used holographic projectors to overlay virtual reality images over physical reality.
- In the movie Iron Man, Tony Stark (Robert Downey Jr.) uses an augmented reality system to design his super-powered suit.
- In the video game Heavy Rain, Norman Jayden, an FBI profiler, possesses a set of experimental augmented reality glasses called an "Added Reality Interface", or ARI. It allows him to rapidly investigate crime scenes and analyze evidence.
- In the Philippines, during their first automated elections (2010), ABS-CBN Broadcasting Corporation used augmented reality during the counting of votes for all National and Local Candidates and in delivering news reports.

Literature

- The table top role-playing game, Shadowrun, introduced AR into its game world. Most of the characters in the game use viewing devices to interact with the AR world most of the time.
- Cybergeneration, a table top role-playing game by R. Talsorian, includes "virtuality", an augmented reality created through v-trodes, cheap, widely available devices people wear at their temples.
- The books Halting State by Charles Stross and Rainbows End by Vernor Vinge include augmented reality primarily in the form of virtual overlays over the real world. Halting State mentions Copspace, which is used by cops, and the use by gamers to overlay their characters onto themselves during a gaming convention. Rainbows End mentions outdoor overlays based on popular fictional universes from H. P. Lovecraft and Terry Pratchett among others.
- The term "Geohacking" has been coined by William Gibson in his book Spook Country, where artists use a combination of GPS and 3D graphics technology to embed rendered meshes in real world landscapes.
- In *The Risen Empire*, by Scott Westerfeld, most - if not all - people have their own "synesthesia". An AR menu unique to the user that is projected in front of them, but they can only see their own synesthesia menus. It is controlled by hand gestures, blink patterns, where the user is looking, clicks of the tongue, etc.
- In the Greg Egan novel *Distress*, the 'Witness' software used to record sights and sounds experienced by the user can be set-up to scan what the user is seeing and highlight people the user is looking out for.
- In the *Revelation Space* series of novels, Alastair Reynolds characters frequently employ "Entoptics" which are essentially a highly developed form of augmented reality, going so far as to entirely substitute natural perception.

See also

- Alternate reality game
- ARQuake
- Augmented browsing
- Augmented virtuality
- Bionic contact lens
- Camera resectioning
- Computer-mediated reality
- Cyborg
- Head-mounted display
- Mixed reality
- Mediated reality
- Simulated reality
- Virtual retinal display
- Virtuality Continuum
- Virtual reality
- Wearable computer

External links

- Media related to Augmented Reality at Wikimedia Commons

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Face detection

Face detection is a **computer technology** that determines the locations and sizes of human faces in arbitrary (digital) images. It detects facial features and ignores anything else, such as buildings, trees and bodies.

Definition and relation to other tasks

Face detection can be regarded as a specific case of **object-class detection**; In object-class detection, the task is to find the locations and sizes of all objects in an image that belong to a given class. Examples include upper torsos, pedestrians, and cars.

Face detection can be regarded as a more general case of **face localization**; In face localization, the task is to find the locations and sizes of a **known** number of faces (usually one). In face detection, one does not have this additional information.

Early face-detection algorithms focused on the detection of frontal human faces, whereas newer algorithms attempt to solve the more general and difficult problem of multi-view face detection. That is, the detection of faces that are either rotated along the axis from the face to the observer (in-plane rotation), or rotated along the vertical or left-right axis (out-of-plane rotation),or both.

Techniques

Face detection as a pattern-classification task

Many algorithms implement the face-detection task as a binary pattern-classification task. That is, the content of a given part of an image is transformed into features, after which a classifier trained on example faces decides whether that particular region of the image is a face, or not.

Often, a window-sliding technique is employed. That is, the classifier is used to classify the (usually square or rectangular) portions of an image, at all locations and scales, as either faces or non-faces (background pattern).

Controlled background

Images with a plain or a static background are easy to process. Remove the background and only the faces will be left, assuming the image only contains a frontal face.

By color

Using skin color to find face segments is a vulnerable technique. The database may not contain all the skin colors possible. Lighting can also affect the results. Non-animate objects with the same color as skin can be picked up since the technique uses color segmentation. The advantages are the lack of restriction to orientation or size of faces and a good algorithm can handle complex backgrounds[1] .

By motion

Faces are usually moving in real-time videos. Calculating the moving area will get the face segment. However, other objects in the video can also be moving and would affect the results. A specific type of motion on faces is blinking. Detecting a blinking pattern in an image sequence can detect the presence of a face[2] . Eyes usually blink together and symmetrically positioned, which eliminates similar motions in the video. Each image is subtracted from the previous image. The difference image will show boundaries of moved pixels. If the eyes happen to be blinking, there will be a small boundary within the face.

Model-based

A face model can contain the appearance, shape, and motion of faces. There are several shapes of faces. Some common ones are oval, rectangle, round, square, heart, and triangle. Motions include, but not limited to, blinking, raised eyebrows, flared nostrils, wrinkled forehead, and opened mouth. The face models will not be able to represent any person making any expression, but the technique does result in an acceptable degree of accuracy[3] . The models are passed over the image to find faces, however this technique works better with face tracking. Once the face is detected, the model is laid over the face and the system is able to track face movements.

Applications

Face detection is used in biometrics, often as a part of (or together with) a facial recognition system. It is also used in video surveillance, human computer interface and image database management. Some recent digital cameras use face detection for autofocus[4] . Also, face detection is useful for selecting regions of interest in photo slideshows that use a pan-and-scale Ken Burns effect so

Face detection is gaining the interest of marketers. A webcam can be integrated into a television and detect any face that walks by. The system then calculates the race, gender, and age range of the face. Once the information is collected, a series of advertisements can be played that is specific toward the detected race/gender/age.

Popular algorithms

- Viola-Jones object detection framework - Viola & Jones [5] (2001)
- Schneiderman & Kanade [6] (2000)
- Rowley, Baluja & Kanade: Neural Network-based Face Detection [7] (1998)

See also

- TSL color space
- Computer vision
- Facial recognition system
- Three-dimensional face recognition
- iPhoto
- Picasa

External links

- Detecting faces in images: a survey [8]
- Open source J2ME code for face detection using a cellphone camera [9]
- Open source Computer Vision library that includes face detection [10]
- Face detection techniques [11]

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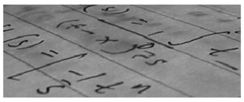
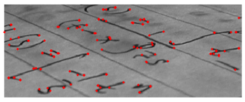
Feature detection (computer vision)

Feature detection
  Output of a typical corner detection algorithm
Edge detection
Canny
Canny-Deriche
Differential
Sobel
Roberts Cross
Interest point detection
Corner detection
Harris operator
Shi and Tomasi
Level curve curvature
SUSAN
FAST
Blob detection
Laplacian of Gaussian (LoG)
Difference of Gaussians (DoG)
Determinant of Hessian (DoH)
Maximally stable extremal regions
PCBR
Hough transform
Ridge detection
Affine invariant feature detection
Affine shape adaptation
Harris affine
Hessian affine
Feature description
SIFT
SURF
GLOH

LESH
Scale-space
Scale-space axioms
Implementation details
Pyramids

In computer vision and image processing the concept of **feature detection** refers to methods that aim at computing abstractions of image information and making local decisions at every image point whether there is an image feature of a given type at that point or not. The resulting features will be subsets of the image domain, often in the form of isolated points, continuous curves or connected regions.

Definition of a feature

There is no universal or exact definition of what constitutes a feature, and the exact definition often depends on the problem or the type of application. Given that, a feature is defined as an "interesting" part of an image, and features are used as a starting point for many computer vision algorithms. Since features are used as the starting point and main primitives for subsequent algorithms, the overall algorithm will often only be as good as its feature detector. Consequently, the desirable property for a feature detector is *repeatability*: whether or not the same feature will be detected in two or more different images of the same scene.

Feature detection is a low-level image processing operation. That is, it is usually performed as the first operation on an image, and examines every pixel to see if there is a feature present at that pixel. If this is part of a larger algorithm, then the algorithm will typically only examine the image in the region of the features. As a built-in pre-requisite to feature detection, the input image is usually smoothed by a Gaussian kernel in a scale-space representation and one or several feature images are computed, often expressed in terms of local derivative operations.

Occasionally, when feature detection is computationally expensive and there are time constraints, a higher level algorithm may be used to guide the feature detection stage, so that only certain parts of the image are searched for features.

Where many computer vision algorithms use feature detection as the initial step, so as a result, a very large number of feature detectors have been developed. These vary widely in the kinds of feature detected, the computational complexity and the repeatability. At an overview level, these feature detectors can (with some overlap) be divided into the following groups:

Types of image features

Edges

Edges are points where there is a boundary (or an edge) between two image regions. In general, an edge can be of almost arbitrary shape, and may include junctions. In practice, edges are usually defined as sets of points in the image which have a strong gradient magnitude. Furthermore, some common algorithms will then chain high gradient points together to form a more complete description of an edge. These algorithms usually place some constraints on the properties of an edge, such as shape, smoothness, and gradient value.

Locally, edges have a one dimensional structure.

Corners / interest points

The terms corners and interest points are used somewhat interchangeably and refer to point-like features in an image, which have a local two dimensional structure. The name "Corner" arose since early algorithms first performed edge detection, and then analysed the edges to find rapid changes in direction (corners). These algorithms were then developed so that explicit edge detection was no longer required, for instance by looking for high levels of curvature in the image gradient. It was then noticed that the so-called corners were also being detected on parts of the image which were not corners in the traditional sense (for instance a small bright spot on a dark background may be detected). These points are frequently known as interest points, but the term "corner" is used by tradition.

Blobs / regions of interest or interest points

Blobs provide a complementary description of image structures in terms of regions, as opposed to corners that are more point-like. Nevertheless, blob descriptors often contain a preferred point (a local maximum of an operator response or a center of gravity) which means that many blob detectors may also be regarded as interest point operators. Blob detectors can detect areas in an image which are too smooth to be detected by a corner detector.

Consider shrinking an image and then performing corner detection. The detector will respond to points which are sharp in the shrunk image, but may be smooth in the original image. It is at this point that the difference between a corner detector and a blob detector becomes somewhat vague. To a large extent, this distinction can be remedied by including an appropriate notion of scale. Nevertheless, due to their response properties to different types of image structures at different scales, the LoG and DoH blob detectors are also mentioned in the article on corner detection.

Ridges

For elongated objects, the notion of *ridges* is a natural tool. A ridge descriptor computed from a grey-level image can be seen as a generalization of a medial axis. From a practical viewpoint, a ridge can be thought of as a one-dimensional curve that represents an axis of symmetry, and in addition has an attribute of local ridge width associated with each ridge point. Unfortunately, however, it is algorithmically harder to extract ridge features from general classes of grey-level images than edge-, corner- or blob features. Nevertheless, ridge descriptors are frequently used for road extraction in aerial images and for extracting blood vessels in medical images -- see ridge detection.

Feature detectors

Common feature detectors and their classification:

Feature detector	Edge	Corner	Blob
Canny	X		
Sobel	X		
Harris & Stephens / Plessey	X	X	
SUSAN	X	X	
Shi & Tomasi		X	
Level curve curvature		X	
FAST		X	
Laplacian of Gaussian		X	X
Difference of Gaussians		X	X
Determinant of Hessian		X	X

MSER			X
PCBR			X
Grey-level blobs			X

Feature extraction

Once features have been detected, a local image patch around the feature can be extracted. This extraction may involve quite considerable amounts of image processing. The result is known as a feature descriptor or feature vector. Among the approaches that are used to feature description, one can mention N-jets and local histograms (see scale-invariant feature transform for one example of a local histogram descriptor). In addition to such attribute information, the feature detection step by itself may also provide complementary attributes, such as the edge orientation and gradient magnitude in edge detection and the polarity and the strength of the blob in blob detection.

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See also

- Edge detection
- Corner detection
- Blob detection
- Ridge detection
- Interest point detection
- Scale-space
- Feature detection
- Feature extraction
- Feature (Computer vision)
- Computer vision

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Lane departure warning system

In road-transport terminology, a **lane departure warning system** is a mechanism designed to warn a driver when the vehicle begins to move out of its lane (unless a turn signal is on in that direction) on freeways and arterial roads. These systems are designed to minimize accidents by addressing the main causes of collisions: driving error, distraction and drowsiness. In 2009 the NHTSA began studying whether to mandate lane departure warning systems and frontal collision warning systems on automobiles.[1]


Roadway with lane markings

There are two main types of systems:

- systems which warn the driver if the vehicle is leaving its lane. (visual, audible, and/or vibration warnings)
- systems which warn the driver and if no action is taken automatically take steps to ensure the vehicle stays in its lane.

The first production lane departure warning system in Europe was developed by the United States's Iteris company for Mercedes Actros commercial trucks. The system debuted in 2000 and is now available on most trucks sold in Europe. In 2002, the Iteris system became available on Freightliner Trucks' trucks in North America. In all of these systems, the driver is warned of unintentional lane departures by an audible rumble strip sound generated on the side of the vehicle drifting out of the lane. If a turn signal is used, no warnings are generated.

Timeline

2001: Nissan Motors began offering a Lane Keeping Support system on the Cima sold in Japan.[2] In 2004, the first passenger vehicle system available in North America was jointly developed by Iteris and Valeo for Nissan on the Infiniti FX and in 2005 the M vehicles.[3] In this system, a camera mounted in the overhead console above the mirror monitors the lane markings on a roadway. A warning tone is triggered when the vehicle begins to drift over the marking to alert the driver. In 2007 Infiniti offered a newer version of this feature, which it calls the *Lane Departure Prevention* (LDP) system. This feature utilizes the vehicle stability control system to help assist the driver maintain lane position by applying gentle brake pressure to the appropriate wheels.[4]

2002: Toyota introduced its Lane Monitoring System[5] on vehicles such as the Cardina[6] and Alphard sold in Japan, this system warns the driver if it appears the vehicle is beginning to drift out of its lane.[7] In 2004, Toyota added a Lane Keeping Assist feature to the Crown Majesta which can apply a small-counter steering force to aid in keeping the vehicle in its lane.[8] In 2006, Lexus introduced a multi-mode Lane Keeping Assist system on the LS 460 which utilizes stereo cameras along with more sophisticated object and pattern recognition processors, this system can issue an audiovisual warning and also using the Electric Power Steering (EPS) steer the vehicle to hold its lane, this system also applies counter-steering torque to help ensure the driver does not over-correct or "saw" the steering wheel while attempting to return the vehicle to its proper lane,[9] if the radar cruise control system is engaged the Lane Keep function works to help reduce the driver's steering input burden by providing steering torque, however the driver must remain active otherwise the system will deactivate.[10] (see a demonstration on YouTube [11])

2003: Honda launched their Lane Keep Assist System (LKAS) on the Inspire.[12] [13] It provides up to 80% of steering torque to keep the car in its lane on the highway. It is also designed to make highway driving less cumbersome by minimizing the driver's steering input.[14] A camera is mounted at the top of the windshield, just above the rear-view mirror scans the road ahead in a 40-degree radius, picking up the dotted white lines used to divide lane boundaries on the highway. The computer recognizes that you're locked into a particular lane, monitors how sharp the curve is and uses factors such as yaw and vehicle speed to calculate what steering input is required.[15]

2005: Citroën became first in Europe to offer LDWS on their 2005 C4 and C5 models, and now also on their C6. This system uses infrared sensors to monitor lane markings on the road surface. A vibration mechanism in the seat alerts the driver of deviations.[16] Audi began in 2007 offering its Audi Lane Assist feature[17] for the first time on the Q7. This system unlike the Japanese "assist" systems will not intervene in the actual driving rather vibrate the steering wheel if the vehicle appears to be exiting its lane. The LDW System in Audi is based on a forward-looking video-camera in visible range as opposed to the downward-looking infrared sensors in Citroën.[18]

2007: General Motors introduced Lane Departure Warning on its 2008 model year Cadillac STS, DTS and Buick Lucerne models. The General Motors system warns the driver, with an audible tone and a warning indicator in the dashboard. BMW also introduced Lane Departure Warning on the 5 series and 6 series using a vibrating steering wheel to warn the driver of unintended departures. Volvo introduced the Lane Departure Warning system along with the Driver Alert Control on its 2008 model year S80 and on the new V70 and XC70 executive cars. Volvo's lane departure warning system uses a camera to track road markings and sound an alarm when drivers depart their lane without signaling. The systems used by BMW, Volvo, and General Motors are based on core technology from Mobileye

2009: Mercedes-Benz began offering a Lane Keeping Assist function on the new E-class.[19] This system warns the driver with a vibrating steering wheel if it appears the vehicle is beginning to leave its lane. And a new feature will automatically deactivate and reactivate if it ascertains the driver is intentionally leaving his lane, for instance if the driver is aggressively cornering. However this system will not automatically correct the vehicle to ensure it stays in its lane like the Japanese "assist" systems.

2010: Kia Motors offers the 2011 Cadenza premium sedan with an optional Lane Departure Warning System (LDWS) in select markets. This system uses a flashing dashboard telltale and emits an audible warning when a white lane marking is being crossed, and emits a louder audible warning when a yellow line marking is crossed. This system is canceled when a turn signal is operating, or by pressing a deactivation switch on the dashboard. The system works by using an optical sensor on both sides of the car.

FIAT is also launching its Lane Keep Assist feature based on TRW lane detect system. Peugeot introduced the same system than Citroën in its new 308.

Lane departure warning systems are now combining prevention with risk reports in the transportation industry. Viewnyx applies video based technologies to assist fleets in lowering their driving liability costs. By providing Safety Managers with driver and fleet risk assessment reports and tools to facilitate proactive coaching & training to eliminate high risk behaviors. The Lookout solution is currently being used by North American fleets. There are first solutions for implementing a lane departure warning system on a mobile phone.[20]

See also

- Precrash system
- Adaptive cruise control
- Blind spot monitor
- Intelligent car
- Advanced front lighting (swiveling headlamps)
- Lane

External links

- Intelligent Vehicle News and Information [21]

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Non-photorealistic rendering

Non-photorealistic rendering (NPR) is an area of computer graphics that focuses on enabling a wide variety of expressive styles for digital art. In contrast to traditional computer graphics, which has focused on photorealism, NPR is inspired by artistic styles such as painting, drawing, technical illustration, and animated cartoons. NPR has appeared in movies and video games in the form of "toon shaders," as well as in architectural illustration and experimental animation. An example of a modern use of this method is that of Cel-shaded animation.

Three-Dimensional NPR Techniques

Three-dimensional NPR is the style that is most commonly seen in video games and movies. The output from this technique is almost always a 3D model that has been modified from the original input model to portray a new artistic style. In many cases, the geometry of the model is identical to the original geometry, and only the material applied to the surface is modified. With increased availability of programmable GPU's, shaders have allowed NPR effects to be applied to the rasterised image that is be displayed to the screen[1] . The majority of NPR techniques applied to 3D geometry are intended to make the scene appear two-dimensional.

Two-Dimensional NPR Techniques

The input to a two-dimensional NPR system is most commonly an image; however, there are systems that take 3D geometry information as input and produce a 2D image or video as output. Again, many of the systems are intended to mimic a desired artistic style, such as watercolor, impressionism, or pen and ink drawing.

NPR for Enhancing Legibility

The most useful illustrations in technical illustrations are not necessarily photorealistic. Non-photorealistic renderings, such as exploded view diagrams, greatly assist in showing placement of parts in a complex system.

Interactive Techniques

Users who are interested in having much more control in the NPR process may be more interested in interactive techniques. Many of these NPR systems provide the user with a canvas that they can "paint" on using the cursor - as the user paints, a stylized version of the image is revealed on the canvas. This is especially useful for people who want to simulate different sizes of brush strokes according to different areas of the image.

Simulating the Artistic Media

In contrast to the methods mentioned previously, another technique in NPR is simulating the painter's medium. Methods include simulating the diffusion of ink through different kinds of paper, and also of pigments through water for simulation of watercolor.

Terminology

The term "non-photorealistic rendering" was probably coined by David Salesin and Georges Winkenbach in a 1994 paper. Many researchers find the terminology to be unsatisfying; some of the criticisms are as follows:

- The term "photorealism" means something different to graphics researchers than it does to artists, who are the target consumers of NPR techniques. For artists, it refers to a school of painting that focuses on reproducing the effect of a camera lens, with all the distortion and hyper-reflections that involves. For graphics researchers, it refers to an image that is visually indistinguishable from reality. In fact, graphics researchers lump the kinds of visual distortions that are used by photorealist painters into non-photorealism.

- Describing something by what it is not is problematic. Equivalent comparisons might be "non-elephant biology", or "non-geometric mathematics". NPR researchers have stated that they expect the term will disappear eventually, and be replaced by the more general term "computer graphics", with "photorealistic graphics" being used to describe traditional computer graphics.
- Many techniques that are used to create 'non-photorealistic' images are not rendering techniques. They are modelling techniques, or post-processing techniques. While the latter are coming to be known as 'image-based rendering', sketch-based modelling techniques, cannot technically be included under this heading, which is very inconvenient for conference organisers.

The first conference on Non-Photorealistic Animation and Rendering included a discussion of possible alternative names. Among those suggested were "expressive graphics", "artistic rendering", "non-realistic graphics", "art-based rendering", and "psychographics". All of these terms have been used in various research papers on the topic, but the term NPR seems to have nonetheless taken hold.

References

Some key papers in the development of NPR are:

- "*Paint by Numbers: Abstract Image Representations*", by Paul Haeberli, SIGGRAPH 90
- "*Comprehensible rendering of 3-D shapes*", by Saito and Takahashi, SIGGRAPH 90
- "*Wet and Sticky: A Novel Model for Computer-Based Painting*", by Tunde Cockshott, PhD Thesis, Glasgow University, 1991
- "*Computer-Generated Pen-and-Ink Illustration*", by Winkenbach and Salesin, SIGGRAPH 94
- "*Interactive Pen-and-Ink Illustration*", by Salisbury, Anderson, Barzel, Salesin, SIGGRAPH 94
- "*Painterly Rendering for Animation*", by Barb Meier, SIGGRAPH 96
- "*A Non-Photorealistic Lighting Model For Automatic Technical Illustration*", by Amy Gooch, Bruce Gooch, Peter Shirley.Elaine Cohen, SIGGRAPH 98

Technical Meetings on NPR

The first technical meeting dedicated to NPR was the ACM sponsored Symposium on Non-Photorealistic Rendering and Animation[2] (NPAR) in 2000. NPAR is traditionally co-located with the Annecy Animated Film Festival[3] , running on even numbered years. From 2007 NPAR began to also run on odd-numbered years, co-located with ACM SIGGRAPH[4] .

Films and software that use NPR

This section lists some seminal uses of NPR techniques in films and software. See the article on cel-shaded animation for a list of uses of toon-shading in games and movies.

Short films

- Technological Threat, 1988. Early use of toon shading together with Tex Avery-style cartoon characters.
- Gas Planet, by Eric Darnell, 1992. Pencil-sketching 3D rendering.
- Fishing by David Gainey, 2000. Watercolor-style 3D rendering.
- RoadHead, 1998 and Snack and Drink, 1999, by Bob Sabiston. Short films created with Rotoshop.
- Ryan, 2004. Nonlinear projection and other distortions of 3D geometry.

Feature films

- What Dreams May Come, 1998. Painterly rendering in the "painted world" sequence.
- Tarzan, 1999. First use of Disney's "Deep Canvas" system.
- Waking Life, 2001. First use of rotoshop in a feature film.
- Sin City, 2005.
- Renaissance, 2006.
- Azur et Asmar, 2006.
- A Scanner Darkly, 2007.
- 300, 2007.
- Bolt, 2008.
- Tangled, 2010.

Video games and other software

- Jet Set Radio, 2000 Early use of toon-shading in video games.
- SketchUp, 2000 Sketch-like modelling software with toon rendering.
- The Legend of Zelda: The Wind Waker, 2002 and Phantom Hourglass, 2007
- XIII (video game), 2003
- Ōkami, 2006
- Team Fortress 2, 2007
- Prince of Persia, 2008
- Valkyria Chronicles, 2008
- Borderlands, 2009

External links

- Paul Haeberli's *Impressionist* applet [5]
- Artistic smoothing applet [6]
- Tunde Cockshott's Wet and Sticky revisited [7]
- Stylized Depiction in Computer Graphics: An annotated survey of online NPR resources [8]
- NPAR conference [9]
- Homepage of freeware program FotoSketcher to turn photos into art [10]

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[4] http://www.siggraph.org
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[6] http://www.cs.rug.nl/~imaging/artisticsmoothing/java/ArtisticApplet.html
[7] http://java.cms.livjm.ac.uk/homepage/staff/cmsdengl/ws
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[9] http://www.npar.org/
[10] http://www.fotosketcher.com/

Medical image processing

Medical imaging is the technique and process used to create images of the human body (or parts and function thereof) for clinical purposes (medical procedures seeking to reveal, diagnose or examine disease) or medical science (including the study of normal anatomy and physiology). Although imaging of removed organs and tissues can be performed for medical reasons, such procedures are not usually referred to as medical imaging, but rather are a part of pathology.

As a discipline and in its widest sense, it is part of biological imaging and incorporates radiology (in the wider sense), nuclear medicine, investigative radiological sciences, endoscopy, (medical) thermography, medical photography and microscopy (e.g. for human pathological investigations).

Measurement and recording techniques which are not primarily designed to produce images, such as electroencephalography (EEG), magnetoencephalography (MEG), Electrocardiography (EKG) and others, but which produce data susceptible to be represented as maps (i.e. containing positional information), can be seen as forms of medical imaging.

Overview

In the clinical context, medical imaging is generally equated to radiology or "clinical imaging" and the medical practitioner responsible for interpreting (and sometimes acquiring) the images is a radiologist. Diagnostic radiography designates the technical aspects of medical imaging and in particular the acquisition of medical images. The *radiographer* or *radiologic technologist* is usually responsible for acquiring medical images of diagnostic quality, although some radiological interventions are performed by radiologists. While radiology is an evaluation of anatomy, nuclear medicine provides functional assessment.

As a field of scientific investigation, medical imaging constitutes a sub-discipline of biomedical engineering, medical physics or medicine depending on the context: Research and development in the area of instrumentation, image acquisition (e.g. radiography), modelling and quantification are usually the preserve of biomedical engineering, medical physics and computer science; Research into the application and interpretation of medical images is usually the preserve of radiology and the medical sub-discipline relevant to medical condition or area of medical science (neuroscience, cardiology, psychiatry, psychology, etc) under investigation. Many of the techniques developed for medical imaging also have scientific and industrial applications.

Medical imaging is often perceived to designate the set of techniques that noninvasively produce images of the internal aspect of the body. In this restricted sense, medical imaging can be seen as the solution of mathematical inverse problems. This means that cause (the properties of living tissue) is inferred from effect (the observed signal). In the case of ultrasonography the probe consists of ultrasonic pressure waves and echoes inside the tissue show the internal structure. In the case of projection radiography, the probe is X-ray radiation which is absorbed at different rates in different tissue types such as bone, muscle and fat.

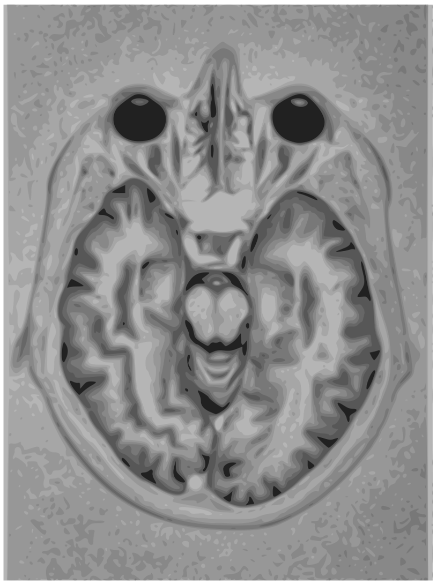
Imaging technology

Radiography

Two forms of radiographic images are in use in medical imaging; projection radiography and fluoroscopy, with the latter being useful for intraoperative and catheter guidance. These 2D techniques are still in wide use despite the advance of 3D tomography due to the low cost, high resolution, and depending on application, lower radiation dosages. This imaging modality utilizes a wide beam of x rays for image acquisition and is the first imaging technique available in modern medicine.

- *Fluoroscopy* produces real-time images of internal structures of the body in a similar fashion to radiography, but employs a constant input of x-rays, at a lower dose rate. Contrast media, such as barium, iodine, and air are used to visualize internal organs as they work. Fluoroscopy is also used in image-guided procedures when constant feedback during a procedure is required. An image receptor is required to convert the radiation into an image after it has passed through the area of interest. Early on this was a fluorescing screen, which gave way to an Image Amplifier (IA) which was a large vacuum tube that had the receiving end coated with cesium iodide, and a mirror at the opposite end. Eventually the mirror was replaced with a TV camera.
- *Projectional radiographs*, more commonly known as x-rays, are often used to determine the type and extent of a fracture as well as for detecting pathological changes in the lungs. With the use of radio-opaque contrast media, such as barium, they can also be used to visualize the structure of the stomach and intestines - this can help diagnose ulcers or certain types of colon cancer.

Magnetic resonance imaging (MRI)



A brain MRI representation

A magnetic resonance imaging instrument (MRI scanner), or "nuclear magnetic resonance (NMR) imaging" scanner as it was originally known, uses powerful magnets to polarise and excite hydrogen nuclei (single proton) in water molecules in human tissue, producing a detectable signal which is spatially encoded, resulting in images of the body. MRI uses three electromagnetic fields: a very strong (on the order of units of teslas) static magnetic field to polarize the hydrogen nuclei, called the static field; a weaker time-varying (on the order of 1 kHz) field(s) for spatial encoding, called the gradient field(s); and a weak radio-frequency (RF) field for manipulation of the hydrogen nuclei to produce measurable signals, collected through an RF antenna.

Like CT, MRI traditionally creates a two dimensional image of a thin "slice" of the body and is therefore considered a tomographic imaging technique. Modern MRI instruments are capable of producing images in the form of 3D blocks, which may be considered a generalisation of the single-slice, tomographic, concept. Unlike CT, MRI does not involve the use of ionizing radiation and is therefore not associated with the same health hazards. For example, because MRI has only been in use since the early 1980s, there are no known long-term effects of exposure to strong static fields (this is the subject of some debate; see 'Safety' in MRI) and therefore there is no limit to the number of scans to which an individual can be subjected, in contrast with X-ray and CT. However, there are well-identified health risks associated with tissue heating from exposure to the RF field and the presence of implanted devices in the body, such as pace makers. These risks are strictly controlled as part of the design of the instrument and the scanning protocols used.

Because CT and MRI are sensitive to different tissue properties, the appearance of the images obtained with the two techniques differ markedly. In CT, X-rays must be blocked by some form of dense tissue to create an image, so the image quality when looking at soft tissues will be poor. In MRI, while any nucleus with a net nuclear spin can be used, the proton of the hydrogen atom remains the most widely used, especially in the clinical setting, because it is so ubiquitous and returns a large signal. This nucleus, present in water molecules, allows the excellent soft-tissue contrast achievable with MRI.

Nuclear medicine

Nuclear medicine encompasses both diagnostic imaging and treatment of disease, and may also be referred to as molecular medicine or molecular imaging & therapeutics [1] . Nuclear medicine uses certain properties of isotopes and the energetic particles emitted from radioactive material to diagnose or treat various pathology. Different from the typical concept of anatomic radiology, nuclear medicine enables assessment of physiology. This function-based approach to medical evaluation has useful applications in most subspecialties, notably oncology, neurology, and cardiology. *Gamma cameras* are used in e.g. scintigraphy, SPECT and PET to detect regions of biologic activity that may be associated with disease. Relatively short lived isotope, such as ^{123}I is administered to the patient. Isotopes are often preferentially absorbed by biologically active tissue in the body, and can be used to identify tumors or fracture points in bone. Images are acquired after collimated photons are detected by a crystal that gives off a light signal, which is in turn amplified and converted into count data.

- *Scintigraphy* ("scint") is a form of diagnostic test wherein radioisotopes are taken internally, for example intravenously or orally. Then, gamma camera capture and form two-dimensional[2] images from the radiation emitted by the radiopharmaceuticals.
- *SPECT* is a 3D tomographic technique that uses gamma camera data from many projections and can be reconstructed in different planes. A dual detector head gamma camera combined with a CT scanner, which provides localization of functional SPECT data, is termed a SPECT/CT camera, and has shown utility in advancing the field of molecular imaging.
- *Positron emission tomography* (PET) uses coincidence detection to image functional processes. Short-lived positron emitting isotope, such as ^{18}F, is incorporated with an organic substance such as glucose, creating F18-fluorodeoxyglucose, which can be used as a marker of metabolic utilization. Images of activity distribution throughout the body can show rapidly growing tissue, like tumor, metastasis, or infection. PET images can be viewed in comparison to computed tomography scans to determine an anatomic correlate. Modern scanners combine PET with a CT, or even MRI, to optimize the image reconstruction involved with positron imaging. This is performed on the same equipment without physically moving the patient off of the gantry. The resultant hybrid of functional and anatomic imaging information is a useful tool in non-invasive diagnosis and patient management.

Photoacoustic imaging

Photoacoustic imaging is a recently developed hybrid biomedical imaging modality based on the photoacoustic effect. It combines the advantages of optical absorption contrast with ultrasonic spatial resolution for deep imaging in (optical) diffusive or quasi-diffusive regime. Recent studies have shown that photoacoustic imaging can be used in vivo for tumor angiogenesis monitoring, blood oxygenation mapping, functional brain imaging, and skin melanoma detection, etc.

Breast Thermography

Digital infrared imaging thermography is based on the principle that metabolic activity and vascular circulation in both pre-cancerous tissue and the area surrounding a developing breast cancer is almost always higher than in normal breast tissue. Cancerous tumors require an ever-increasing supply of nutrients and therefore increase circulation to their cells by holding open existing blood vessels, opening dormant vessels, and creating new ones (neoangiogenesis). This process frequently results in an increase in regional surface temperatures of the breast. Digital infrared imaging uses extremely sensitive medical infrared cameras and sophisticated computers to detect, analyze, and produce high-resolution diagnostic images of these temperature variations. Because of DII's sensitivity, these temperature variations may be among the earliest signs of breast cancer and/or a pre-cancerous state of the breast[3] .

Tomography

Tomography is the method of imaging a single plane, or slice, of an object resulting in a tomogram. There are several forms of tomography:

- Linear tomography: This is the most basic form of tomography. The X-ray tube moved from point "A" to point "B" above the patient, while the cassette holder (or "bucky") moves simultaneously under the patient from point "B" to point "A." The fulcrum, or pivot point, is set to the area of interest. In this manner, the points above and below the focal plane are blurred out, just as the background is blurred when panning a camera during exposure. No longer carried out and replaced by computed tomography.
- Poly tomography: This was a complex form of tomography. With this technique, a number of geometrical movements were programmed, such as hypocycloidic, circular, figure 8, and elliptical. Philips Medical Systems [4] produced one such device called the 'Polytome.' This unit was still in use into the 1990s, as its resulting images for small or difficult physiology, such as the inner ear, was still difficult to image with CTs at that time. As the resolution of CTs got better, this procedure was taken over by the CT.
- Zonography: This is a variant of linear tomography, where a limited arc of movement is used. It is still used in some centres for visualising the kidney during an intravenous urogram (IVU).
- Orthopantomography (OPT or OPG): The only common tomographic examination in use. This makes use of a complex movement to allow the radiographic examination of the mandible, as if it were a flat bone. It is often referred to as a "Panorex", but this is incorrect, as it is a trademark of a specific company.
- Computed Tomography (CT), or Computed Axial Tomography (CAT: A CT scan, also known as a CAT scan, is a helical tomography (latest generation), which traditionally produces a 2D image of the structures in a thin section of the body. It uses X-rays. It has a greater ionizing radiation dose burden than projection radiography; repeated scans must be limited to avoid health effects.

Ultrasound

Medical ultrasonography uses high frequency broadband sound waves in the megahertz range that are reflected by tissue to varying degrees to produce (up to 3D) images. This is commonly associated with imaging the fetus in pregnant women. Uses of ultrasound are much broader, however. Other important uses include imaging the abdominal organs, heart, breast, muscles, tendons, arteries and veins. While it may provide less anatomical detail than techniques such as CT or MRI, it has several advantages which make it ideal in numerous situations, in particular that it studies the function of moving structures in real-time, emits no ionizing radiation, and contains speckle that can be used in elastography. It is very safe to use and does not appear to cause any adverse effects, although information on this is not well documented. It is also relatively inexpensive and quick to perform. Ultrasound scanners can be taken to critically ill patients in intensive care units, avoiding the danger caused while moving the patient to the radiology department. The real time moving image obtained can be used to guide drainage and biopsy procedures. Doppler capabilities on modern scanners allow the blood flow in arteries and veins to be assessed.

Medical imaging topics

Maximizing imaging procedure use

The amount of data obtained in a single MR or CT scan is very extensive. Some of the data that radiologists discard could save patients time and money, while reducing their exposure to radiation and risk of complications from invasive procedures.[5]

Creation of three-dimensional images

Recently, techniques have been developed to enable CT, MRI and ultrasound scanning software to produce 3D images for the physician.[6] Traditionally CT and MRI scans produced 2D static output on film. To produce 3D images, many scans are made, then combined by computers to produce a 3D model, which can then be manipulated by the physician. 3D ultrasounds are produced using a somewhat similar technique. In diagnosing disease of the viscera of abdomen,ultrasound is particularly sensitive on imaging of biliary tract,urinary tract and female reproductive organs(ovary,fallopian tubes).As for example,diagnosis of gall stone by dilatation of common bile duct and stone in common bile duct . With the ability to visualize important structures in great detail, 3D visualization methods are a valuable resource for the diagnosis and surgical treatment of many pathologies. It was a key resource for the famous, but ultimately unsuccessful attempt by Singaporean surgeons to separate Iranian twins Ladan and Laleh Bijani in 2003. The 3D equipment was used previously for similar operations with great success.

Other proposed or developed techniques include:

- Diffuse optical tomography
- Elastography
- Electrical impedance tomography
- Optoacoustic imaging
- Ophthalmology
  - A-scan
  - B-scan
  - Corneal topography
  - Optical coherence tomography
  - Scanning laser ophthalmoscopy

Some of these techniques are still at a research stage and not yet used in clinical routines.

Compression of medical images

Medical imaging techniques produce very large amounts of data, especially from CT, MRI and PET modalities. As a result, storage and communications of electronic image data are prohibitive without the use of compression. JPEG 2000 is the state-of-the-art image compression DICOM standard for storage and transmission of medical images. The cost and feasibility of accessing large image data sets over low or various bandwidths are further addressed by use of another DICOM standard, called JPIP, to enable efficient streaming of the JPEG 2000 compressed image data.

Non-diagnostic imaging

Neuroimaging has also been used in experimental circumstances to allow people (especially disabled persons) to control outside devices, acting as a brain computer interface.

Archiving and recording

Used primarily in ultrasound imaging, capturing the image a medical imaging device is required for archiving and telemedicine applications. In most scenarios, a frame grabber is used in order to capture the video signal from the medical device and relay it to a computer for further processing and operations.[7]

Open source software for medical image analysis

Several open source software packages are available for performing analysis of medical images:

- ImageJ
- 3D Slicer
- ITK
- OsiriX
- GemIdent
- MicroDicom
- FreeSurfer
- FreePlugin

Use in pharmaceutical clinical trials

Medical imaging has become a major tool in clinical trials since it enables rapid diagnosis with visualization and quantitative assessment.

A typical clinical trial goes through multiple phases and can take up to eight years. Clinical endpoints or outcomes are used to determine whether the therapy is safe and effective. Once a patient reaches the endpoint, he/she is generally excluded from further experimental interaction. Trials that rely solely on clinical endpoints are very costly as they have long durations and tend to need large number of patients.

In contrast to clinical endpoints, surrogate endpoints have been shown to cut down the time required to confirm whether a drug has clinical benefits. Imaging biomarkers (a characteristic that is objectively measured by an imaging technique, which is used as an indicator of pharmacological response to a therapy) and surrogate endpoints have shown to facilitate the use of small group sizes, obtaining quick results with good statistical power.[8]

Imaging is able to reveal subtle change that is indicative of the progression of therapy that may be missed out by more subjective, traditional approaches. Statistical bias is reduced as the findings are evaluated without any direct patient contact.

For example, measurement of tumour shrinkage is a commonly used surrogate endpoint in solid tumour response evaluation. This allows for faster and more objective assessment of the effects of anticancer drugs. In evaluating the extent of Alzheimer’s disease, it is still prevalent to use behavioural and cognitive tests. MRI scans on the entire brain can accurately pinpoint hippocampal atrophy rate while PET scans is able to measure the brain’s metabolic activity by measuring regional glucose metabolism.[8]

An imaging-based trial will usually be made up of three components:

1. A realistic imaging protocol. The protocol is an outline that standardizes (as far as practically possible) the way in which the images are acquired using the various modalities (PET, SPECT, CT, MRI). It covers the specifics in which images are to be stored, processed and evaluated.
2. An imaging centre that is responsible for collecting the images, perform quality control and provide tools for data storage, distribution and analysis. It is important for images acquired at different time points are displayed in a

standardised format to maintain the reliability of the evaluation. Certain specialised imaging contract research organizations provide to end medical imaging services, from protocol design and site management through to data quality assurance and image analysis.

3. Clinical sites that recruit patients to generate the images to send back to the imaging centre.

See also

- Preclinical imaging
- Cardiac PET
- Biomedical informatics
- Digital Imaging and Communications in Medicine
- Digital Mammography and PACS
- EMMI European Master in Molecular Imaging
- Fotofinder
- Full-body scan
- VoluMedic
- Magnetic field imaging
- Medical examination
- Medical radiography
- Medical test
- Neuroimaging
- Non-invasive (medical)
- PACS
- JPEG 2000 compression
- JPIP streaming
- Pneumoencephalogram
- Radiology information system
- Segmentation (image processing)
- Signal-to-noise ratio
- Society for Imaging Science and Technology
- Tomogram
- Virtopsy

Further reading

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Microscope image processing

Microscope image processing is a broad term that covers the use of digital image processing techniques to process, analyze and present images obtained from a microscope. Such processing is now commonplace in a number of diverse fields such as medicine, biological research, cancer research, drug testing, metallurgy, etc. A number of manufacturers of microscopes now specifically design in features that allow the microscopes to interface to an image processing system.

Image acquisition

Until the early 1990s, most image acquisition in video microscopy applications was typically done with an analog video camera, often simply closed circuit TV cameras. While this required the use of a frame grabber to digitize the images, video cameras provided images at full video frame rate (25-30 frames per second) allowing live video recording and processing. While the advent of solid state detectors yielded several advantages, the real-time video camera was actually superior in many respects.

Today, acquisition is usually done using a CCD camera mounted in the optical path of the microscope. The camera may be full colour or monochrome. Very often, very high resolution cameras are employed to gain as much direct information as possible. Cryogenic cooling is also common, to minimise noise. Often digital cameras used for this application provide pixel intensity data to a resolution of 12-16 bits, much higher than is used in consumer imaging products.

Ironically, in recent years, much effort has been put into acquiring data at video rates, or higher (25-30 frames per second or higher). What was once easy with off-the-shelf video cameras now requires special, high speed electronics to handle the vast digital data bandwidth.

Higher speed acquisition allows dynamic processes to be observed in real time, or stored for later playback and analysis. Combined with the high image resolution, this approach can generate vast quantities of raw data, which can be a challenge to deal with, even with a modern computer system.

It should be observed that while current CCD detectors allow very high image resolution, often this involves a trade-off because, for a given chip size, as the pixel count increases, the pixel size decreases. As the pixels get smaller, their well depth decreases, reducing the number of electrons that can be stored. In turn, this results in a poorer signal to noise ratio.

For best results, one must select an appropriate sensor for a given application. Because microscope images have an intrinsic limiting resolution, it often makes little sense to use a noisy, high resolution detector for image acquisition. A more modest detector, with larger pixels, can often produce much higher quality images because of reduced noise. This is especially important in low-light applications such as fluorescence microscopy.

Moreover, one must also consider the temporal resolution requirements of the application. A lower resolution detector will often have a significantly higher acquisition rate, permitting the observation of faster events. Conversely, if the observed object is motionless, one may wish to acquire images at the highest possible spatial resolution without regard to the time required to acquire a single image.

2D image techniques

Image processing for microscopy application begins with fundamental techniques intended to most accurately reproduce the information contained in the microscopic sample. This might include adjusting the brightness and contrast of the image, averaging images to reduce image noise and correcting for illumination non-uniformities. Such processing involves only basic arithmetic operations between images (i.e. addition, subtraction, multiplication and division). The vast majority of processing done on microscope image is of this nature.

Another class of common 2D operations called image convolution are often used to reduce or enhance image details. Such "blurring" and "sharpening" algorithms in most programs work by altering a pixel's value based on a weighted sum of that and the surrounding pixels. (a more detailed description of kernel based convolution deserves an entry for itself).

Other basic two dimensional techniques include operations such as image rotation, warping, color balancing etc.

At times, advanced techniques are employed with the goal of "undoing" the distortion of the optical path of the microscope, thus eliminating distortions and blurring caused by the instrumentation. This process is called deconvolution, and a variety of algorithms have been developed, some of great mathematical complexity. The end result is an image far sharper and clearer than could be obtained in the optical domain alone. This is typically a 3-dimensional operation, that analyzes a volumetric image (i.e. images taken at a variety of focal planes through the sample) and uses this data to reconstruct a more accurate 3-dimensional image.

3D image techniques

Another common requirement is to take a series of images at a fixed position, but at different focal depths. Since most microscopic samples are essentially transparent, and the depth of field of the focused sample is exceptionally narrow, it is possible to capture images "through" a three-dimensional object using 2D equipment like confocal microscopes. Software is then able to reconstruct a 3D model of the original sample which may be manipulated appropriately. The processing turns a 2D instrument into a 3D instrument, which would not otherwise exist. In recent times this technique has led to a number of scientific discoveries in cell biology.

Analysis

Analysis of images will vary considerably according to application. Typical analysis includes determining where the edges of an object are, counting similar objects, calculating the area, perimeter length and other useful measurements of each object. A common approach is to create an image mask which only includes pixels that match certain criteria, then perform simpler scanning operations on the resulting mask. It is also possible to label objects and track their motion over a series of frames in a video sequence.

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See also

- Image processing
- ImageJ
- FIJI (software)
- Endrov
- GemIdent

External links

- Quantitative Microscopy [1]
- 3-D Image Processing in Microscopy [2]
- Sampling theorem [3] - Nyquist sampling in digital microscopy

References

[1] http://www.ph.tn.tudelft.nl/People/young/manuscripts/QM/QM.html
[2] http://www.med.uni-giessen.de/ipl/iplcourse.html
[3] http://www.vanosta.be/pcrnyq.htm

Morphological image processing

Mathematical morphology (MM) is a theory and technique for the analysis and processing of geometrical structures, based on set theory, lattice theory, topology, and random functions. MM is most commonly applied to digital images, but it can be employed as well on graphs, surface meshes, solids, and many other spatial structures.

A shape (in blue) and its morphological dilation (in green) and erosion (in yellow) by a diamond-shape structuring element.

Topological and geometrical continuous-space concepts such as size, shape, convexity, connectivity, and geodesic distance, can be characterized by MM on both continuous and discrete spaces. MM is also the foundation of morphological image processing, which consists of a set of operators that transform images according to the above characterizations.

MM was originally developed for binary images, and was later extended to grayscale functions and images. The subsequent generalization to complete lattices is widely accepted today as MM's theoretical foundation.

History

Mathematical Morphology was born in 1964 from the collaborative work of Georges Matheron and Jean Serra, at the *École des Mines de Paris*, France. Matheron supervised the PhD thesis of Serra, devoted to the quantification of mineral characteristics from thin cross sections, and this work resulted in a novel practical approach, as well as theoretical advancements in integral geometry and topology.

In 1968, the *Centre de Morphologie Mathématique* was founded by the École des Mines de Paris in Fontainebleau, France, lead by Matheron and Serra.

During the rest of the 1960's and most of the 1970's, MM dealt essentially with binary images, treated as sets, and generated a large number of binary operators and techniques: Hit-or-miss transform, dilation, erosion, opening, closing, granulometry, thinning, skeletonization, ultimate erosion, conditional bisector, and others. A random approach was also developed, based on novel image models. Most of the work in that period was developed in Fontainebleau.

From mid-1970's to mid-1980's, MM was generalized to grayscale functions and images as well. Besides extending the main concepts (such as dilation, erosion, etc...) to functions, this generalization yielded new operators, such as morphological gradients, top-hat transform and the Watershed (MM's main segmentation approach).

In the 1980's and 1990's, MM gained a wider recognition, as research centers in several countries began to adopt and investigate the method. MM started to be applied to a large number of imaging problems and applications.

In 1986, Jean Serra further generalized MM, this time to a theoretical framework based on complete lattices. This generalization brought flexibility to the theory, enabling its application to a much larger number of structures, including color images, video, graphs, meshes, etc... At the same time, Matheron and Serra also formulated a theory for morphological filtering, based on the new lattice framework.

The 1990's and 2000's also saw further theoretical advancements, including the concepts of *connections* and *levelings*.

In 1993, the first International Symposium on Mathematical Morphology (ISMM) took place in Barcelona, Spain. Since then, ISMMs are organized every 2-3 years, each time in a different part of the world: Fontainebleau, France (1994); Atlanta, USA (1996); Amsterdam, Netherlands (1998); Palo Alto, CA, USA (2000); Sydney, Australia (2002); Paris, France (2004); Rio de Janeiro, Brazil (2007); and Groningen, Netherlands (2009).

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- "Appendix A: The 'Centre de Morphologie Mathématique', an overview" by Jean Serra, in (Serra *et al.* (Eds.) 1994), pgs. 369-374.
- "Foreword" in (Ronse *et al.* (Eds.) 2005)

Binary morphology

In binary morphology, an image is viewed as a subset of an Euclidean space $\mathbb{R}^d$ or the integer grid $\mathbb{Z}^d$, for some dimension *d*.

Structuring element

The basic idea in binary morphology is to probe an image with a simple, pre-defined shape, drawing conclusions on how this shape fits or misses the shapes in the image. This simple "probe" is called structuring element, and is itself a binary image (i.e., a subset of the space or grid).

Here are some examples of widely used structuring elements (denoted by *B*):

- Let $E = \mathbb{R}^2$; *B* is an open disk of radius *r*, centered at the origin.
- Let $E = \mathbb{Z}^2$; *B* is a 3x3 square, that is, *B*={(-1,-1), (-1,0), (-1,1), (0,-1), (0,0), (0,1), (1,-1), (1,0), (1,1)}.
- Let $E = \mathbb{Z}^2$; *B* is the "cross" given by: *B*={(-1,0), (0,-1), (0,0), (0,1), (1,0)}.

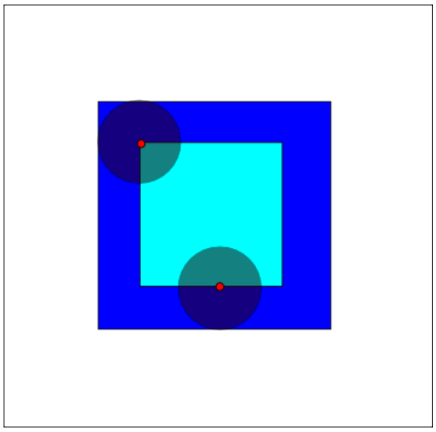
Basic operators

The basic operations are shift-invariant (translation invariant) operators strongly related to Minkowski addition.

Let *E* be a Euclidean space or an integer grid, and *A* a binary image in *E*.

Erosion

The erosion of the binary image *A* by the structuring element *B* is defined by:



The erosion of the dark-blue square by a disk, resulting in the light-blue square.

$$A \ominus B = \{z \in E | B_z \subseteq A\},$$

where B_z is the translation of *B* by the vector z, i.e., $B_z = \{b + z | b \in B\}$, $\forall z \in E$.

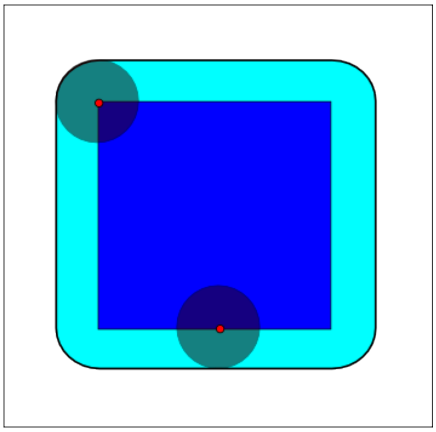
When the structuring element *B* has a center (e.g., *B* is a disk or a square), and this center is located on the origin of *E*, then the erosion of *A* by *B* can be understood as the locus of points reached by the center of *B* when *B* moves inside *A*. For example, the erosion of a square of side 10, centered at the origin, by a disc of radius 2, also centered at the origin, is a square of side 6 centered at the origin.

The erosion of *A* by *B* is also given by the expression: $A \ominus B = \bigcap_{b \in B} A_{-b}$.

Example application: Assume we have received a fax of a dark photocopy. Everything looks like it was written with a pen that is bleeding. Erosion process will allow thicker lines to get skinny and detect the hole inside the letter "o".

Dilation

The dilation of *A* by the structuring element *B* is defined by:



The dilation of the dark-blue square by a disk, resulting in the light-blue square with rounded corners.

$$A \oplus B = \bigcup_{b \in B} A_b .$$

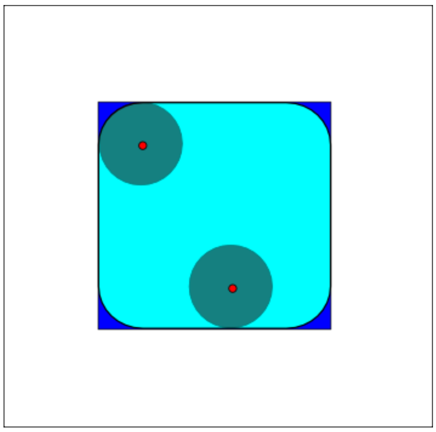
The dilation is commutative, also given by: $A \oplus B = B \oplus A = \bigcup_{a \in A} B_a .$

If *B* has a center on the origin, as before, then the dilation of *A* by *B* can be understood as the locus of the points covered by *B* when the center of *B* moves inside *A*. In the above example, the dilation of the square of side 10 by the disk of radius 2 is a square of side 14, with rounded corners, centered at the origin. The radius of the rounded corners is 2.

The dilation can also be obtained by: $A \oplus B = \{z \in E | (B^s)_z \cap A \neq \varnothing\}$, where B^s denotes the symmetric of *B*, that is, $B^s = \{x \in E | -x \in B\}$.
Example application: Dilation is the opposite of the erosion. Figures that are very lightly drawn get thick when "dilated". Easiest way to describe it is to imagine the same fax/text is written with a thicker pen.

Opening

The opening of *A* by *B* is obtained by the erosion of *A* by *B*, followed by dilation of the resulting image by *B*:



The opening of the dark-blue square by a disk, resulting in the light-blue square with round corners.

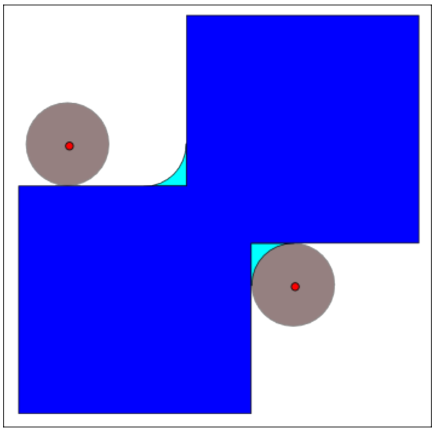
$$A \circ B = (A \ominus B) \oplus B .$$

The opening is also given by $A \circ B = \bigcup_{B_x \subseteq A} B_x$, which means that it is the locus of translations of the structuring element *B* inside the image *A*. In the case of the square of radius 10, and a disc of radius 2 as the structuring element, the opening is a square of radius 10 with rounded corners, where the corner radius is 2.

Example application: Let's assume someone has written a note on a non-soaking paper that writing looks like it is growing tiny hairy roots all over. Opening essentially removes the outer tiny "hairline" leaks and restores the text. The side effect is that it rounds off things. The sharp edges start to disappear.

Closing

The closing of *A* by *B* is obtained by the dilation of *A* by *B*, followed by erosion of the resulting structure by *B*:



The closing of the dark-blue shape (union of two squares) by a disk, resulting in the union of the dark-blue shape and the light-blue areas.

$$A \bullet B = (A \oplus B) \ominus B.$$

The closing can also be obtained by $A \bullet B = (A^c \circ B^s)^c$, where X^c denotes the complement of *X* relative to *E* (that is, $X^c = \{x \in E | x \notin X\}$). The above means that the closing is the complement of the locus of translations of the symmetric of the structuring element outside the image *A*.

Properties of the basic operators

Here are some properties of the basic binary morphological operators (dilation, erosion, opening and closing):

- They are translation invariant.
- They are increasing, that is, if $A \subseteq C$, then $A \oplus B \subseteq C \oplus B$, and $A \ominus B \subseteq C \ominus B$, etc.
- The dilation is commutative.
- If the origin of *E* belongs to the structuring element *B*, then $A \ominus B \subseteq A \circ B \subseteq A \subseteq A \bullet B \subseteq A \oplus B$.
- The dilation is associative, i.e., $(A \oplus B) \oplus C = A \oplus (B \oplus C)$. Moreover, the erosion satisfies $(A \ominus B) \ominus C = A \ominus (B \oplus C)$.
- Erosion and dilation satisfy the duality $A \oplus B = (A^c \ominus B^s)^c$.
- Opening and closing satisfy the duality $A \bullet B = (A^c \circ B^s)^c$.
- The dilation is distributive over set union
- The erosion is distributive over set intersection
- The dilation is a pseudo-inverse of the erosion, and vice-versa, in the following sense: $A \subseteq (C \ominus B)$ if and only if $(A \oplus B) \subseteq C$.
- Opening and closing are idempotent.
- Opening is anti-extensive, i.e., $A \circ B \subseteq A$, whereas the closing is extensive, i.e., $A \subseteq A \bullet B$.

Other operators and tools

- Hit-or-miss transform
- Morphological skeleton
- Filtering by reconstruction
- Ultimate erosions and conditional bisectors
- Granulometry
- Geodesic distance functions

Grayscale morphology

In grayscale morphology, images are functions mapping an Euclidean space or grid *E* into $\mathbb{R}\cup\{\infty,-\infty\}$, where $\mathbb{R}$ is the set of reals, ∞ is an element larger than any real number, and $-\infty$ is an element smaller than any real number.
Grayscale structuring elements are also functions of the same format, called "structuring functions".

Denoting an image by *f(x)* and the structuring function by *b(x)*, the grayscale dilation of *f* by *b* is given by

$$(f\oplus b)(x)=\sup_{y\in E}[f(y)+b(x-y)],$$

where "sup" denotes the supremum.

Similarly, the erosion of *f* by *b* is given by

$$(f\ominus b)(x)=\inf_{y\in E}[f(y)-b(y-x)],$$

where "inf" denotes the infimum.

Just like in binary morphology, the opening and closing are given respectively by

$f\circ b=(f\ominus b)\oplus b$, and

$f\bullet b=(f\oplus b)\ominus b$.

Flat structuring functions

It is common to use flat structuring elements in morphological applications. Flat structuring functions are functions *b(x)* in the form

$$b(x)=\begin{cases}0, & x\in B,\\ -\infty, & \text{otherwise}\end{cases},$$

where $B\subseteq E$.

In this case, the dilation and erosion are greatly simplified, and given respectively by

$(f\oplus b)(x)=\sup_{z\in B^s}f(z-x)$, and

$(f\ominus b)(x)=\inf_{z\in B}f(z-x)$.

In the bounded, discrete case (*E* is a grid and *B* is bounded), the supremum and infimum operators can be replaced by the maximum and minimum. Thus, dilation and erosion are particular cases of order statistics filters, with dilation returning the maximum value within a moving window (the symmetric of the structuring function support *B*), and the erosion returning the minimum value within the moving window *B*.

In the case of flat structuring element, the morphological operators depend only on the relative ordering of pixel values, regardless their numerical values, and therefore are especially suited to the processing of binary images and grayscale images whose light transfer function is not known.

Other operators and tools

- Morphological Gradients
- Top-hat transform
- Watershed (algorithm)

By combining these operators one can obtain algorithms for many image processing tasks, such as feature detection, image segmentation, image sharpening, image filtering, and classification.

Mathematical morphology on complete lattices

Complete lattices are partially ordered sets, where every subset has an infimum and a supremum. In particular, it contains a least element and a greatest element (also denoted "universe").

Adjunctions (Dilation and Erosion)

Let $(L, \leq)$ be a complete lattice, with infimum and minimum symbolized by $\wedge$ and $\vee$, respectively. Its universe and least element are symbolized by *U* and $\emptyset$, respectively. Moreover, let $\{X_i\}$ be a collection of elements from *L*.
A dilation is any operator $\delta : L \rightarrow L$ that distributes over the supremum, and preserves the least element. I.e.:

- $\bigvee_i \delta(X_i) = \delta\left(\bigvee_i X_i\right)$,
- $\delta(\emptyset) = \emptyset$.

An erosion is any operator $\varepsilon : L \rightarrow L$ that distributes over the infimum, and preserves the universe. I.e.:

- $\bigwedge_i \varepsilon(X_i) = \varepsilon\left(\bigwedge_i X_i\right)$,
- $\varepsilon(U) = U$.

Dilations and erosions form Galois connections. That is, for all dilation δ there is one and only one erosion ε that satisfies

$$X \leq \varepsilon(Y) \Leftrightarrow \delta(X) \leq Y$$

for all $X, Y \in L$.

Similarly, for all erosion there is one and only one dilation satisfying the above connection.

Furthermore, if two operators satisfy the connection, then δ must be a dilation, and ε an erosion.

Pairs of erosions and dilations satisfying the above connection are called "adjunctions", and the erosion is said to be the adjoint erosion of the dilation, and vice-versa.

Opening and Closing

For all adjunction (ε, δ), the morphological opening $\gamma : L \rightarrow L$ and morphological closing $\phi : L \rightarrow L$ are defined as follows:

$\gamma = \delta\varepsilon$, and

$\phi = \varepsilon\delta$.

The morphological opening and closing are particular cases of algebraic opening (or simply opening) and algebraic closing (or simply closing). Algebraic openings are operators in *L* that are idempotent, increasing, and anti-extensive. Algebraic closings are operators in *L* that are idempotent, increasing, and extensive.

Particular cases

Binary morphology is a particular case of lattice morphology, where *L* is the power set of *E* (Euclidean space or grid), that is, *L* is the set of all subsets of *E*, and $\leq$ is the set inclusion. In this case, the infimum is set intersection, and the supremum is set union.

Similarly, grayscale morphology is another particular case, where *L* is the set of functions mapping *E* into $\mathbb{R}\cup\{\infty,-\infty\}$, and $\leq$, $\vee$, and $\wedge$, are the point-wise order, supremum, and infimum, respectively. That is, is *f* and *g* are functions in *L*, then $f\leq g$ if and only if $f(x)\leq g(x),\forall x\in E$; the infimum $f\wedge g$ is given by $(f\wedge g)(x)=f(x)\wedge g(x)$; and the supremum $f\vee g$ is given by $(f\vee g)(x)=f(x)\vee g(x)$.

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- *Mathematical Morphology: 40 Years On*, Christian Ronse, Laurent Najman, and Etienne Decencière (Eds.), ISBN 1-4020-3442-3 (2005)
- *Mathematical Morphology and its Applications to Signal and Image Processing*, Gerald J.F. Banon, Junior Barrera, Ulisses M. Braga-Neto (Eds.), proceedings of the 8th international symposium on mathematical morphology (ISMM'07), ISBN 978-85-17-00032-4 (2007)

External links

- Online course on mathematical morphology [1], by Jean Serra (in English, French, and Spanish)
- Center of Mathematical Morphology [2], Paris School of Mines
- History of Mathematical Morphology [3], by Georges Matheron and Jean Serra
- Morphology Digest, a newsletter on mathematical morphology [4], by Pierre Soille
- Lectures on Image Processing: A collection of 18 lectures in pdf format from Vanderbilt University. Lectures 16-18 are on Mathematical Morphology [3], by Alan Peters
- Mathematical Morphology; from Computer Vision lectures [5], by Robyn Owens
- Free SIMD Optimized Image processing library [6]
- Java applet demonstration [7]
- FILTERS : a free open source image processing library [8]
- Fast morphological erosions, dilations, openings, and closings [9]

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[1] http://cmm.ensmp.fr/~serra/cours/index.htm
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[4] http://mdigest.jrc.ec.europa.eu
[5] http://homepages.inf.ed.ac.uk/rbf/CVonline/LOCAL_COPIES/OWENS/LECT3/node3.html
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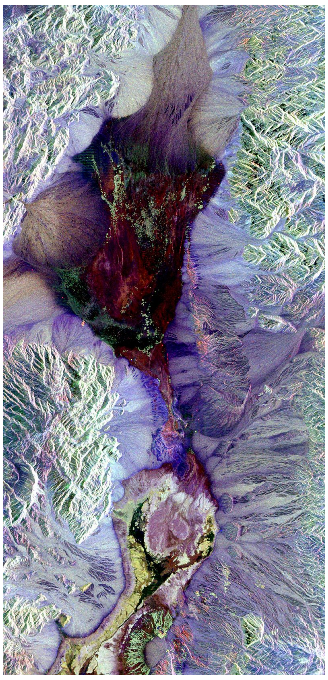
Remote sensing

Remote sensing is the small or large-scale acquisition of information of an object or phenomenon, by the use of either recording or real-time sensing device(s) that are wireless, or not in physical or intimate contact with the object (such as by way of aircraft, spacecraft, satellite, buoy, or ship). In practice, remote sensing is the stand-off collection through the use of a variety of devices for gathering information on a given object or area. Thus, Earth observation or weather satellite collection platforms, ocean and atmospheric observing weather buoy platforms, the monitoring of a parolee via an ultrasound identification system, Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET), X-radiation (X-RAY) and space probes are all examples of remote sensing. In modern usage, the term generally refers to the use of imaging sensor technologies including: instruments found in aircraft and spacecraft as well as those used in electrophysiology, and is distinct from other imaging-related fields such as medical imaging.



Synthetic aperture radar image of Death Valley colored using polarimetry.

There are two main types of remote sensing: passive remote sensing and active remote sensing. Passive sensors detect natural radiation that is emitted or reflected by the object or surrounding area being observed. Reflected sunlight is the most common source of radiation measured by passive sensors. Examples of passive remote sensors include film photography, Infrared, charge-coupled devices, and radiometers. Active collection, on the other hand, emits energy in order to scan objects and areas whereupon a sensor then detects and measures the radiation that is reflected or backscattered from the target. RADAR is an example of active remote sensing where the time delay between emission and return is measured, establishing the location, height, speed and direction of an object.

Remote sensing makes it possible to collect data on dangerous or inaccessible areas. Remote sensing applications include monitoring deforestation in areas such as the Amazon Basin, the effects of climate change on glaciers and Arctic and Antarctic regions, and depth sounding of coastal and ocean depths. Military collection during the cold war made use of stand-off collection of data about dangerous border areas. Remote sensing also replaces costly and slow data collection on the ground, ensuring in the process that areas or objects are not disturbed.

Orbital platforms collect and transmit data from different parts of the electromagnetic spectrum, which in conjunction with larger scale aerial or ground-based sensing and analysis, provides researchers with enough information to monitor trends such as El Niño and other natural long and short term phenomena. Other uses include different areas of the earth sciences such as natural resource management, agricultural fields such as land usage and conservation, and national security and overhead, ground-based and stand-off collection on border areas.[1]

Data acquisition techniques

The basis for multi-spectral collection and analysis is that of examined areas or objects that reflect or emit radiation that stand out from surrounding areas.

Applications of remote sensing data

- Conventional radar is mostly associated with aerial traffic control, early warning, and certain large scale meteorological data. Doppler radar is used by local law enforcements' monitoring of speed limits and in enhanced meteorological collection such as wind speed and direction within weather systems. Other types of active collection includes plasmas in the ionosphere). Interferometric synthetic aperture radar is used to produce precise digital elevation models of large scale terrain (See RADARSAT, TerraSAR-X, Magellan).
- Laser and radar altimeters on satellites have provided a wide range of data. By measuring the bulges of water caused by gravity, they map features on the seafloor to a resolution of a mile or so. By measuring the height and wave-length of ocean waves, the altimeters measure wind speeds and direction, and surface ocean currents and directions.
- Light detection and ranging (LIDAR) is well known in the examples of weapon ranging, laser illuminated homing of projectiles.LIDAR discovered by hendy in 1976. LIDAR is used to detect and measure the concentration of various chemicals in the atmosphere, while airborne LIDAR can be used to measure heights of objects and features on the ground more accurately than with radar technology. Vegetation remote sensing is a principle application of LIDAR.
- Radiometers and photometers are the most common instrument in use, collecting reflected and emitted radiation in a wide range of frequencies. The most common are visible and infrared sensors, followed by microwave, gamma ray and rarely, ultraviolet. They may also be used to detect the emission spectra of various chemicals, providing data on chemical concentrations in the atmosphere.
- Stereographic pairs of aerial photographs have often been used to make topographic maps by imagery and terrain analysts in trafficability and highway departments for potential routes.
- Simultaneous multi-spectral platforms such as Landsat have been in use since the 70's. These thematic mappers take images in multiple wavelengths of electro-magnetic radiation (multi-spectral) and are usually found on earth observation satellites, including (for example) the Landsat program or the IKONOS satellite. Maps of land cover and land use from thematic mapping can be used to prospect for minerals, detect or monitor land usage, deforestation, and examine the health of indigenous plants and crops, including entire farming regions or forests.
- Within the scope of the combat against desertification, remote sensing allows to follow-up and monitor risk areas in the long term, to determine desertification factors, to support decision-makers in defining relevant measures of environmental management, and to assess their impacts.[2]

Geodetic

- Overhead geodetic collection was first used in aerial submarine detection and gravitational data used in military maps. This data revealed minute perturbations in the Earth's gravitational field (geodesy) that may be used to determine changes in the mass distribution of the Earth, which in turn may be used for geological or hydrological studies.

Acoustic and near-acoustic

- Sonar: *passive sonar*, listening for the sound made by another object (a vessel, a whale etc); *active sonar*, emitting pulses of sounds and listening for echoes, used for detecting, ranging and measurements of underwater objects and terrain.
- Seismograms taken at different locations can locate and measure earthquakes (after they occur) by comparing the relative intensity and precise timing.

To coordinate a series of large-scale observations, most sensing systems depend on the following: platform location, what time it is, and the rotation and orientation of the sensor. High-end instruments now often use positional information from satellite navigation systems. The rotation and orientation is often provided within a degree or two with electronic compasses. Compasses can measure not just azimuth (i.e. degrees to magnetic north), but also altitude (degrees above the horizon), since the magnetic field curves into the Earth at different angles at different latitudes. More exact orientations require gyroscopic-aided orientation, periodically realigned by different methods including navigation from stars or known benchmarks.

Resolution impacts collection and is best explained with the following relationship: less resolution=less detail & larger coverage, More resolution=more detail, less coverage. The skilled management of collection results in cost-effective collection and avoid situations such as the use of multiple high resolution data which tends to clog transmission and storage infrastructure.

Data processing

Generally speaking, remote sensing works on the principle of the *inverse problem*. While the object or phenomenon of interest (the **state**) may not be directly measured, there exists some other variable that can be detected and measured (the **observation**), which may be related to the object of interest through the use of a data-derived computer model. The common analogy given to describe this is trying to determine the type of animal from its footprints. For example, while it is impossible to directly measure temperatures in the upper atmosphere, it is possible to measure the spectral emissions from a known chemical species (such as carbon dioxide) in that region. The frequency of the emission may then be related to the temperature in that region via various thermodynamic relations.

The quality of remote sensing data consists of its spatial, spectral, radiometric and temporal resolutions.

Spatial resolution

: The size of a pixel that is recorded in a raster image - typically pixels may correspond to square areas ranging in side length from 1 to 1000 metres (3.3 to 3300 ft).

Spectral resolution

: The wavelength width of the different frequency bands recorded - usually, this is related to the number of frequency bands recorded by the platform. Current Landsat collection is that of seven bands, including several in the infra-red spectrum, ranging from a spectral resolution of 0.07 to 2.1 μm. The Hyperion sensor on Earth Observing-1 resolves 220 bands from 0.4 to 2.5 μm, with a spectral resolution of 0.10 to 0.11 μm per band.

Radiometric resolution

The number of different intensities of radiation the sensor is able to distinguish. Typically, this ranges from 8 to 14 bits, corresponding to 256 levels of the gray scale and up to 16,384 intensities or "shades" of colour, in each band. It also depends on the instrument noise.

Temporal resolution

The frequency of flyovers by the satellite or plane, and is only relevant in time-series studies or those requiring an averaged or mosaic image as in deforesting monitoring. This was first used by the intelligence community where repeated coverage revealed changes in infrastructure, the deployment of units or the modification/introduction of equipment. Cloud cover over a given area or object makes it necessary to repeat the collection of said location.

In order to create sensor-based maps, most remote sensing systems expect to extrapolate sensor data in relation to a reference point including distances between known points on the ground. This depends on the type of sensor used. For example, in conventional photographs, distances are accurate in the center of the image, with the distortion of measurements increasing the farther you get from the center. Another factor is that of the platen against which the film is pressed can cause severe errors when photographs are used to measure ground distances. The step in which this problem is resolved is called georeferencing, and involves computer-aided matching up of points in the image (typically 30 or more points per image) which is extrapolated with the use of an established benchmark, "warping" the image to produce accurate spatial data. As of the early 1990s, most satellite images are sold fully georeferenced.

In addition, images may need to be radiometrically and atmospherically corrected.

Radiometric correction

gives a scale to the pixel values, e.g. the monochromatic scale of 0 to 255 will be converted to actual radiance values.

Atmospheric correction

eliminates atmospheric haze by rescaling each frequency band so that its minimum value (usually realised in water bodies) corresponds to a pixel value of 0. The digitizing of data also make possible to manipulate the data by changing gray-scale values.

Interpretation is the critical process of making sense of the data. The first application was that of aerial photographic collection which used the following process; spatial measurement through the use of a light table in both conventional single or stereographic coverage, added skills such as the use of photogrammetry, the use of photomosaics, repeat coverage, Making use of objects' known dimensions in order to detect modifications. Image Analysis is the recently developed automated computer-aided application which is in increasing use.

Object-Based Image Analysis (OBIA) is a sub-discipline of GIScience devoted to partitioning remote sensing (RS) imagery into meaningful image-objects, and assessing their characteristics through spatial, spectral and temporal scale.

Old data from remote sensing is often valuable because it may provide the only long-term data for a large extent of geography. At the same time, the data is often complex to interpret, and bulky to store. Modern systems tend to store the data digitally, often with lossless compression. The difficulty with this approach is that the data is fragile, the format may be archaic, and the data may be easy to falsify. One of the best systems for archiving data series is as computer-generated machine-readable ultrafiche, usually in typefonts such as OCR-B, or as digitized half-tone images. Ultrafiches survive well in standard libraries, with lifetimes of several centuries. They can be created, copied, filed and retrieved by automated systems. They are about as compact as archival magnetic media, and yet can be read by human beings with minimal, standardized equipment.

Data processing levels

To facilitate the discussion of data processing in practice, several processing “levels” were first defined in 1986 by NASA as part of its Earth Observing System [3] and steadily adopted since then, both internally at NASA (e.g., [4]) and elsewhere (e.g., [5]); these definitions are:

Level	Description
0	Reconstructed, unprocessed instrument and payload data at full resolution, with any and all communications artifacts (e.g., synchronization frames, communications headers, duplicate data) removed.
1a	Reconstructed, unprocessed instrument data at full resolution, time-referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters (e.g., platform ephemeris) computed and appended but not applied to the Level 0 data (or if applied, in a manner that level 0 is fully recoverable from level 1a data).
1b	Level 1a data that have been processed to sensor units (e.g., radar backscatter cross section, brightness temperature, etc.); not all instruments have Level 1b data; level 0 data is not recoverable from level 1b data.
2	Derived geophysical variables (e.g., ocean wave height, soil moisture, ice concentration) at the same resolution and location as Level 1 source data.
3	Variables mapped on uniform space-time grid scales, usually with some completeness and consistency (e.g., missing points interpolated, complete regions mosaicked together from multiple orbits, etc).
4	Model output or results from analyses of lower level data (i.e., variables that were not measured by the instruments but instead are derived from these measurements).

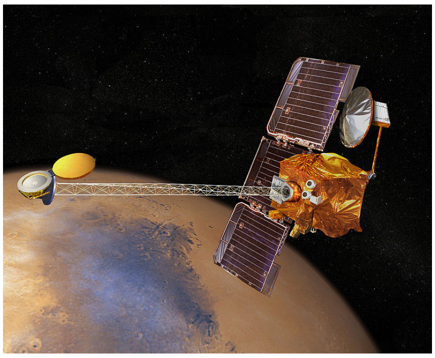
A Level 1 data record is the most fundamental (i.e., highest reversible level) data record that has significant scientific utility, and is the foundation upon which all subsequent data sets are produced. Level 2 is the first level that is directly usable for most scientific applications; its value is much greater than the lower levels. Level 2 data sets tend to be less voluminous than Level 1 data because they have been reduced temporally, spatially, or spectrally. Level 3 data sets are generally smaller than lower level data sets and thus can be dealt with without incurring a great deal of data handling overhead. These data tend to be generally more useful for many applications. The regular spatial and temporal organization of Level 3 datasets makes it feasible to readily combine data from different sources.

History

Beyond the primitive methods of remote sensing our earliest ancestors used (ex.: standing on a high cliff or tree to view the landscape), the modern discipline arose with the development of flight. The balloonist G. Tournachon (alias Nadar) made photographs of Paris from his balloon in 1858. Messenger pigeons, kites, rockets and unmanned balloons were also used for early images. With the exception of balloons, these first, individual images were not particularly useful for map making or for scientific purposes.

The TR-1 reconnaissance/surveillance aircraft.

Systematic aerial photography was developed for military surveillance and reconnaissance purposes beginning in World War I and reaching a climax during the Cold War with the use of modified combat aircraft such as the P-51, P-38, RB-66 and the F-4C, or specifically designed collection platforms such as the U2/TR-1, SR-71, A-5 and the OV-1 series both in overhead and stand-off collection. A more recent development is that of increasingly smaller sensor pods such as those used by law enforcement and the military, in both manned and unmanned platforms. The advantage of this approach is that this requires minimal modification to a given airframe. Later imaging technologies would include Infra-red, conventional, doppler and synthetic aperture radar.



The *2001 Mars Odyssey* used spectrometers and imagers to hunt for evidence of past or present water and volcanic activity on Mars.

The development of artificial satellites in the latter half of the 20th century allowed remote sensing to progress to a global scale as of the end of the Cold War. Instrumentation aboard various Earth observing and weather satellites such as Landsat, the Nimbus and more recent missions such as RADARSAT and UARS provided global measurements of various data for civil, research, and military purposes. Space probes to other planets have also provided the opportunity to conduct remote sensing studies in extraterrestrial environments, synthetic aperture radar aboard the Magellan spacecraft provided detailed topographic maps of Venus, while instruments aboard SOHO allowed studies to be performed on the Sun and the solar wind, just to name a few examples.

Recent developments include, beginning in the 1960s and 1970s with the development of image processing of satellite imagery. Several research groups in Silicon Valley including NASA Ames Research Center, GTE and ESL Inc. developed Fourier transform techniques leading to the first notable enhancement of imagery data.

The introduction of online web services for easy access to remote sensing data in the 21st century (mainly low/medium-resolution images), like Google Earth, has made remote sensing more familiar to the big public and has popularized the science.

Remote Sensing software

Remote Sensing data is processed and analyzed with computer software, known as a remote sensing application. A large number of proprietary and open source applications exist to process remote sensing data. According to an NOAA Sponsored Research by Global Marketing Insights, Inc. the most used applications among Asian academic groups involved in remote sensing are as follows: ERDAS 36% (ERDAS IMAGINE 25% & ERMapper 11%); ESRI 30%; ITT Visual Information Solutions ENVI 17%; MapInfo 17%. Among Western Academic respondents as follows: ESRI 39%, ERDAS IMAGINE 27%, MapInfo 9%, AutoDesk 7%, ITT Visual Information Solutions ENVI 17%. Other important Remote Sensing Software packages include PCI Geomatics who makes PCI Geomatica, the leading remote sensing software package in Canada, IDRISI from Clark Labs, and the original object based image analysis software eCognition from Definiens. Dragon/ips is one of the oldest remote sensing packages still available, and is in some cases free. Open source remote sensing software includes GRASS GIS, QGIS, OSSIM, Opticks (software) and Orfeo toolbox.

See also

- Aerial photography
- Airborne Real-time Cueing Hyperspectral Enhanced Reconnaissance
- Agricultural Camera
- Archaeological imagery
- Cartography
- CLidar
- Coastal management
- Full Spectral Imaging
- Geographic information system (GIS)
- Geoinformatics
- Geophysical survey
- Global Positioning System (GPS)
- Hyperspectral
- IEEE Geoscience and Remote Sensing [6]
- Imagery Analysis
- Imaging Science
- Land cover
- Lidar
- List of Earth observation satellites
- Multispectral pattern recognition
- National Center for Remote Sensing, Air, and Space Law
- National LIDAR Dataset
- Orthophoto
- Pictometry
- Sonar
- Radar
  - Weather radar
- Radiometry
- Remote sensing (archaeology)
- Satellite
- Space probe
- Vector Map
- TopoFlight

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Medical imaging

Medical imaging is the technique and process used to create images of the human body (or parts and function thereof) for clinical purposes (medical procedures seeking to reveal, diagnose or examine disease) or medical science (including the study of normal anatomy and physiology). Although imaging of removed organs and tissues can be performed for medical reasons, such procedures are not usually referred to as medical imaging, but rather are a part of pathology.

As a discipline and in its widest sense, it is part of biological imaging and incorporates radiology (in the wider sense), nuclear medicine, investigative radiological sciences, endoscopy, (medical) thermography, medical photography and microscopy (e.g. for human pathological investigations).

Measurement and recording techniques which are not primarily designed to produce images, such as electroencephalography (EEG), magnetoencephalography (MEG), Electrocardiography (EKG) and others, but which produce data susceptible to be represented as maps (i.e. containing positional information), can be seen as forms of medical imaging.

Overview

In the clinical context, medical imaging is generally equated to radiology or "clinical imaging" and the medical practitioner responsible for interpreting (and sometimes acquiring) the images is a radiologist. Diagnostic radiography designates the technical aspects of medical imaging and in particular the acquisition of medical images. The *radiographer* or *radiologic technologist* is usually responsible for acquiring medical images of diagnostic quality, although some radiological interventions are performed by radiologists. While radiology is an evaluation of anatomy, nuclear medicine provides functional assessment.

As a field of scientific investigation, medical imaging constitutes a sub-discipline of biomedical engineering, medical physics or medicine depending on the context: Research and development in the area of instrumentation, image acquisition (e.g. radiography), modelling and quantification are usually the preserve of biomedical engineering, medical physics and computer science; Research into the application and interpretation of medical images is usually the preserve of radiology and the medical sub-discipline relevant to medical condition or area of medical science (neuroscience, cardiology, psychiatry, psychology, etc) under investigation. Many of the techniques developed for medical imaging also have scientific and industrial applications.

Medical imaging is often perceived to designate the set of techniques that noninvasively produce images of the internal aspect of the body. In this restricted sense, medical imaging can be seen as the solution of mathematical inverse problems. This means that cause (the properties of living tissue) is inferred from effect (the observed signal). In the case of ultrasonography the probe consists of ultrasonic pressure waves and echoes inside the tissue show the internal structure. In the case of projection radiography, the probe is X-ray radiation which is absorbed at different rates in different tissue types such as bone, muscle and fat.

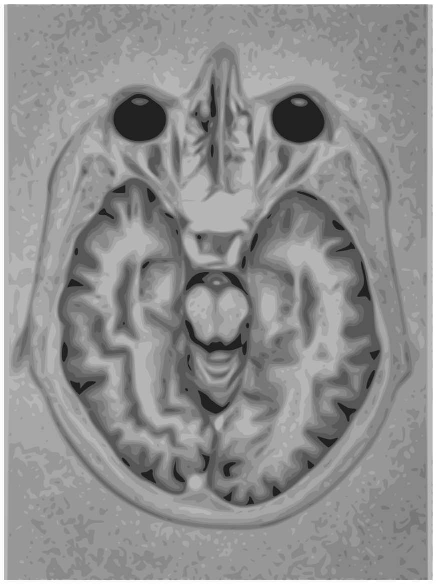
Imaging technology

Radiography

Two forms of radiographic images are in use in medical imaging; projection radiography and fluoroscopy, with the latter being useful for intraoperative and catheter guidance. These 2D techniques are still in wide use despite the advance of 3D tomography due to the low cost, high resolution, and depending on application, lower radiation dosages. This imaging modality utilizes a wide beam of x rays for image acquisition and is the first imaging technique available in modern medicine.

- *Fluoroscopy* produces real-time images of internal structures of the body in a similar fashion to radiography, but employs a constant input of x-rays, at a lower dose rate. Contrast media, such as barium, iodine, and air are used to visualize internal organs as they work. Fluoroscopy is also used in image-guided procedures when constant feedback during a procedure is required. An image receptor is required to convert the radiation into an image after it has passed through the area of interest. Early on this was a fluorescing screen, which gave way to an Image Amplifier (IA) which was a large vacuum tube that had the receiving end coated with cesium iodide, and a mirror at the opposite end. Eventually the mirror was replaced with a TV camera.
- *Projectional radiographs*, more commonly known as x-rays, are often used to determine the type and extent of a fracture as well as for detecting pathological changes in the lungs. With the use of radio-opaque contrast media, such as barium, they can also be used to visualize the structure of the stomach and intestines - this can help diagnose ulcers or certain types of colon cancer.

Magnetic resonance imaging (MRI)


A brain MRI representation

A magnetic resonance imaging instrument (MRI scanner), or "nuclear magnetic resonance (NMR) imaging" scanner as it was originally known, uses powerful magnets to polarise and excite hydrogen nuclei (single proton) in water molecules in human tissue, producing a detectable signal which is spatially encoded, resulting in images of the body. MRI uses three electromagnetic fields: a very strong (on the order of units of teslas) static magnetic field to polarize the hydrogen nuclei, called the static field; a weaker time-varying (on the order of 1 kHz) field(s) for spatial encoding, called the gradient field(s); and a weak radio-frequency (RF) field for manipulation of the hydrogen nuclei to produce measurable signals, collected through an RF antenna.

Like CT, MRI traditionally creates a two dimensional image of a thin "slice" of the body and is therefore considered a tomographic imaging technique. Modern MRI instruments are capable of producing images in the form of 3D blocks, which may be considered a generalisation of the single-slice, tomographic, concept. Unlike CT, MRI does not involve the use of ionizing radiation and is therefore not associated with the same health hazards. For example, because MRI has only been in use since the early 1980s, there are no known long-term effects of exposure to strong static fields (this is the subject of some debate; see 'Safety' in MRI) and therefore there is no limit to the number of scans to which an individual can be subjected, in contrast with X-ray and CT. However, there are well-identified health risks associated with tissue heating from exposure to the RF field and the presence of implanted devices in the body, such as pace makers. These risks are strictly controlled as part of the design of the instrument and the scanning protocols used.

Because CT and MRI are sensitive to different tissue properties, the appearance of the images obtained with the two techniques differ markedly. In CT, X-rays must be blocked by some form of dense tissue to create an image, so the image quality when looking at soft tissues will be poor. In MRI, while any nucleus with a net nuclear spin can be used, the proton of the hydrogen atom remains the most widely used, especially in the clinical setting, because it is so ubiquitous and returns a large signal. This nucleus, present in water molecules, allows the excellent soft-tissue contrast achievable with MRI.

Nuclear medicine

Nuclear medicine encompasses both diagnostic imaging and treatment of disease, and may also be referred to as molecular medicine or molecular imaging & therapeutics [1] . Nuclear medicine uses certain properties of isotopes and the energetic particles emitted from radioactive material to diagnose or treat various pathology. Different from the typical concept of anatomic radiology, nuclear medicine enables assessment of physiology. This function-based approach to medical evaluation has useful applications in most subspecialties, notably oncology, neurology, and cardiology. *Gamma cameras* are used in e.g. scintigraphy, SPECT and PET to detect regions of biologic activity that may be associated with disease. Relatively short lived isotope, such as ^{123}I is administered to the patient. Isotopes are often preferentially absorbed by biologically active tissue in the body, and can be used to identify tumors or fracture points in bone. Images are acquired after collimated photons are detected by a crystal that gives off a light signal, which is in turn amplified and converted into count data.

- *Scintigraphy* ("scint") is a form of diagnostic test wherein radioisotopes are taken internally, for example intravenously or orally. Then, gamma camera capture and form two-dimensional[2] images from the radiation emitted by the radiopharmaceuticals.
- *SPECT* is a 3D tomographic technique that uses gamma camera data from many projections and can be reconstructed in different planes. A dual detector head gamma camera combined with a CT scanner, which provides localization of functional SPECT data, is termed a SPECT/CT camera, and has shown utility in advancing the field of molecular imaging.
- *Positron emission tomography* (PET) uses coincidence detection to image functional processes. Short-lived positron emitting isotope, such as ^{18}F, is incorporated with an organic substance such as glucose, creating F18-fluorodeoxyglucose, which can be used as a marker of metabolic utilization. Images of activity distribution throughout the body can show rapidly growing tissue, like tumor, metastasis, or infection. PET images can be viewed in comparison to computed tomography scans to determine an anatomic correlate. Modern scanners combine PET with a CT, or even MRI, to optimize the image reconstruction involved with positron imaging. This is performed on the same equipment without physically moving the patient off of the gantry. The resultant hybrid of functional and anatomic imaging information is a useful tool in non-invasive diagnosis and patient management.

Photoacoustic imaging

Photoacoustic imaging is a recently developed hybrid biomedical imaging modality based on the photoacoustic effect. It combines the advantages of optical absorption contrast with ultrasonic spatial resolution for deep imaging in (optical) diffusive or quasi-diffusive regime. Recent studies have shown that photoacoustic imaging can be used in vivo for tumor angiogenesis monitoring, blood oxygenation mapping, functional brain imaging, and skin melanoma detection, etc.

Breast Thermography

Digital infrared imaging thermography is based on the principle that metabolic activity and vascular circulation in both pre-cancerous tissue and the area surrounding a developing breast cancer is almost always higher than in normal breast tissue. Cancerous tumors require an ever-increasing supply of nutrients and therefore increase circulation to their cells by holding open existing blood vessels, opening dormant vessels, and creating new ones (neoangiogenesis). This process frequently results in an increase in regional surface temperatures of the breast. Digital infrared imaging uses extremely sensitive medical infrared cameras and sophisticated computers to detect, analyze, and produce high-resolution diagnostic images of these temperature variations. Because of DII's sensitivity, these temperature variations may be among the earliest signs of breast cancer and/or a pre-cancerous state of the breast[3] .

Tomography

Tomography is the method of imaging a single plane, or slice, of an object resulting in a tomogram. There are several forms of tomography:

- Linear tomography: This is the most basic form of tomography. The X-ray tube moved from point "A" to point "B" above the patient, while the cassette holder (or "bucky") moves simultaneously under the patient from point "B" to point "A." The fulcrum, or pivot point, is set to the area of interest. In this manner, the points above and below the focal plane are blurred out, just as the background is blurred when panning a camera during exposure. No longer carried out and replaced by computed tomography.
- Poly tomography: This was a complex form of tomography. With this technique, a number of geometrical movements were programmed, such as hypocycloidic, circular, figure 8, and elliptical. Philips Medical Systems [4] produced one such device called the 'Polytome.' This unit was still in use into the 1990s, as its resulting images for small or difficult physiology, such as the inner ear, was still difficult to image with CTs at that time. As the resolution of CTs got better, this procedure was taken over by the CT.
- Zonography: This is a variant of linear tomography, where a limited arc of movement is used. It is still used in some centres for visualising the kidney during an intravenous urogram (IVU).
- Orthopantomography (OPT or OPG): The only common tomographic examination in use. This makes use of a complex movement to allow the radiographic examination of the mandible, as if it were a flat bone. It is often referred to as a "Panorex", but this is incorrect, as it is a trademark of a specific company.
- Computed Tomography (CT), or Computed Axial Tomography (CAT: A CT scan, also known as a CAT scan, is a helical tomography (latest generation), which traditionally produces a 2D image of the structures in a thin section of the body. It uses X-rays. It has a greater ionizing radiation dose burden than projection radiography; repeated scans must be limited to avoid health effects.

Ultrasound

Medical ultrasonography uses high frequency broadband sound waves in the megahertz range that are reflected by tissue to varying degrees to produce (up to 3D) images. This is commonly associated with imaging the fetus in pregnant women. Uses of ultrasound are much broader, however. Other important uses include imaging the abdominal organs, heart, breast, muscles, tendons, arteries and veins. While it may provide less anatomical detail than techniques such as CT or MRI, it has several advantages which make it ideal in numerous situations, in particular that it studies the function of moving structures in real-time, emits no ionizing radiation, and contains speckle that can be used in elastography. It is very safe to use and does not appear to cause any adverse effects, although information on this is not well documented. It is also relatively inexpensive and quick to perform. Ultrasound scanners can be taken to critically ill patients in intensive care units, avoiding the danger caused while moving the patient to the radiology department. The real time moving image obtained can be used to guide drainage and biopsy procedures. Doppler capabilities on modern scanners allow the blood flow in arteries and veins to be assessed.

Medical imaging topics

Maximizing imaging procedure use

The amount of data obtained in a single MR or CT scan is very extensive. Some of the data that radiologists discard could save patients time and money, while reducing their exposure to radiation and risk of complications from invasive procedures.[4]

Creation of three-dimensional images

Recently, techniques have been developed to enable CT, MRI and ultrasound scanning software to produce 3D images for the physician.[5] Traditionally CT and MRI scans produced 2D static output on film. To produce 3D images, many scans are made, then combined by computers to produce a 3D model, which can then be manipulated by the physician. 3D ultrasounds are produced using a somewhat similar technique. In diagnosing disease of the viscera of abdomen,ultrasound is particularly sensitive on imaging of biliary tract,urinary tract and female reproductive organs(ovary,fallopian tubes).As for example,diagnosis of gall stone by dilatation of common bile duct and stone in common bile duct . With the ability to visualize important structures in great detail, 3D visualization methods are a valuable resource for the diagnosis and surgical treatment of many pathologies. It was a key resource for the famous, but ultimately unsuccessful attempt by Singaporean surgeons to separate Iranian twins Ladan and Laleh Bijani in 2003. The 3D equipment was used previously for similar operations with great success.

Other proposed or developed techniques include:

- Diffuse optical tomography
- Elastography
- Electrical impedance tomography
- Optoacoustic imaging
- Ophthalmology
  - A-scan
  - B-scan
  - Corneal topography
  - Optical coherence tomography
  - Scanning laser ophthalmoscopy

Some of these techniques are still at a research stage and not yet used in clinical routines.

Compression of medical images

Medical imaging techniques produce very large amounts of data, especially from CT, MRI and PET modalities. As a result, storage and communications of electronic image data are prohibitive without the use of compression. JPEG 2000 is the state-of-the-art image compression DICOM standard for storage and transmission of medical images. The cost and feasibility of accessing large image data sets over low or various bandwidths are further addressed by use of another DICOM standard, called JPIP, to enable efficient streaming of the JPEG 2000 compressed image data.

Non-diagnostic imaging

Neuroimaging has also been used in experimental circumstances to allow people (especially disabled persons) to control outside devices, acting as a brain computer interface.

Archiving and recording

Used primarily in ultrasound imaging, capturing the image a medical imaging device is required for archiving and telemedicine applications. In most scenarios, a frame grabber is used in order to capture the video signal from the medical device and relay it to a computer for further processing and operations.[6]

Open source software for medical image analysis

Several open source software packages are available for performing analysis of medical images:

- ImageJ
- 3D Slicer
- ITK
- OsiriX
- GemIdent
- MicroDicom
- FreeSurfer
- FreePlugin

Use in pharmaceutical clinical trials

Medical imaging has become a major tool in clinical trials since it enables rapid diagnosis with visualization and quantitative assessment.

A typical clinical trial goes through multiple phases and can take up to eight years. Clinical endpoints or outcomes are used to determine whether the therapy is safe and effective. Once a patient reaches the endpoint, he/she is generally excluded from further experimental interaction. Trials that rely solely on clinical endpoints are very costly as they have long durations and tend to need large number of patients.

In contrast to clinical endpoints, surrogate endpoints have been shown to cut down the time required to confirm whether a drug has clinical benefits. Imaging biomarkers (a characteristic that is objectively measured by an imaging technique, which is used as an indicator of pharmacological response to a therapy) and surrogate endpoints have shown to facilitate the use of small group sizes, obtaining quick results with good statistical power.[7]

Imaging is able to reveal subtle change that is indicative of the progression of therapy that may be missed out by more subjective, traditional approaches. Statistical bias is reduced as the findings are evaluated without any direct patient contact.

For example, measurement of tumour shrinkage is a commonly used surrogate endpoint in solid tumour response evaluation. This allows for faster and more objective assessment of the effects of anticancer drugs. In evaluating the extent of Alzheimer’s disease, it is still prevalent to use behavioural and cognitive tests. MRI scans on the entire brain can accurately pinpoint hippocampal atrophy rate while PET scans is able to measure the brain’s metabolic activity by measuring regional glucose metabolism.[7]

An imaging-based trial will usually be made up of three components:

1. A realistic imaging protocol. The protocol is an outline that standardizes (as far as practically possible) the way in which the images are acquired using the various modalities (PET, SPECT, CT, MRI). It covers the specifics in which images are to be stored, processed and evaluated.
2. An imaging centre that is responsible for collecting the images, perform quality control and provide tools for data storage, distribution and analysis. It is important for images acquired at different time points are displayed in a

standardised format to maintain the reliability of the evaluation. Certain specialised imaging contract research organizations provide to end medical imaging services, from protocol design and site management through to data quality assurance and image analysis.

3. Clinical sites that recruit patients to generate the images to send back to the imaging centre.

See also

- Preclinical imaging
- Cardiac PET
- Biomedical informatics
- Digital Imaging and Communications in Medicine
- Digital Mammography and PACS
- EMMI European Master in Molecular Imaging
- Fotofinder
- Full-body scan
- VoluMedic
- Magnetic field imaging
- Medical examination
- Medical radiography
- Medical test
- Neuroimaging
- Non-invasive (medical)
- PACS
- JPEG 2000 compression
- JPIP streaming
- Pneumoencephalogram
- Radiology information system
- Segmentation (image processing)
- Signal-to-noise ratio
- Society for Imaging Science and Technology
- Tomogram
- Virtopsy

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- Using JPIP for Standard-Compliant Sharing of Medical Image Data [10] a white paper by Aware Inc. [11]

External links

- Medical imaging [12] at the Open Directory Project
- Medical Image Database [13] Free Indexed Online Images
- http://www.aware.com/imaging/accuradjpip.htm What is JPIP?

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