2D and 3D imaging in medicine

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Figure 3

- **Scene**
- **Digitized Scene**
- **Sampling** → $I(k, l)$
- **Quantization** → Grey levels
- **Acquisition**
- **Preprocessing**
- **Segmentation**
- **Description**
- **Classification**
- **Interpretation**
- **Identification**
- **Research Areas**

- **Sensor** → ADC

- **Coding, Storage**
- **Enhancement**
- **Regions, Contours**
Figure 2

3D models
\textit{object coords.} \\
(a)

3D scene
\textit{scene coords.} \\
(b)

3D scene
\textit{scene coords.} \\
(c)

2D scene
\textit{device coords.} \\

machine calls
\textit{device coords.}
Figure 1

observer  projection plane  scene

virtual camera
**Figure captions.**

Fig.1: The virtual camera paradigm. After having been composed, the “scene” is projected, as seen by an observer taking a snapshot picture. For medical imaging applications, the house, tree and kids should be replaced by voxels or by triangulated solids! Rather than a central projection, as illustrated here, a parallel projection can be used.

Fig.2: The visualization pipeline; (a) scene composition by geometric transformations (e.g. rotation, translation, scaling); (b) clipping into the 3D window (part of the 3D scene that will be projected); (c) projection of the 3D window onto the 2D viewport (part of the 2D projection plane onto which the scene is projected) according to the selected point of view; (b) and (c) are the viewing transformations. Three coordinate systems are defined: object coordinates, for describing an isolated object in the model base; scene coordinates, for describing the common system into which all objects are “put” by means of the geometrical transformations; device coordinates, for the display.

Figure 3: The generic image analysis pipeline.
• Computerized Medical Imaging and Graphics (Pergamon Press);
  IEEE Trans. on Medical Imaging (IEEE).

Image synthesis, processing, analysis and computer vision journals, with frequent medical imaging articles:

• Computer Graphics (ACM);
• Computer Graphics and Applications (IEEE);
• Computer Graphics Forum (North Holland);
• Computer Vision, Graphics and Image Processing (Academic Press);
• Image and Vision Computing (Butterworths);
• Pattern Recognition (Pergamon Press);
• Pattern Recognition Letters (North-Holland);
• Signal Processing (North-Holland).

(Bio)medical journals that regularly publish articles related to medical imaging:

• Advanced Imaging;
• Applied and Theoretical Electrophoresis (Electrophoresis Society);
• Artificial Intelligence in Medicine (Elsevier);
• Biomedical Computing (Elsevier);
• Computer Applic. in the Biosciences - CABIOS (IRL - Oxford Univ. Press);
• Computer Methods and Programs in Biomedicine (Elsevier);
• Computers in Biology and Medicine;
• Electrophoresis (Intern. Electrophoresis Soc.);
• IEEE Trans. on Biomedical Engineering (IEEE);
• IEEE Trans. on Nuclear Sciences (IEEE);
• International Journal of Biomedical Computing;
• Journal of Microscopy;
• Journal of Nuclear Medicine;
• Journal of Scanning Microscopy;
• MD Computing;
• Neurosurgery;
• Nuclear Medicine and Biology (Pergamon);
• Physica Medica (GESA);
• Physics in Medicine and Biology (The Institute of Physics);
• Radiology;
• Ultramicroscopy (Elsevier);
• Ultrasonic Imaging;
• etc.


7.2 Medical imaging journals

Exclusively medical imaging:
medical laboratories. Relying on these rather classical methods, various trends are emerging. New detectors are being developed, which should lead to less invasive and more precise imaging modalities. Functional imaging is becoming commonly used, for discovering and understanding functional structures; coupled with anatomical data, this leads to multimodality imaging, aiming to study the correlation between structure and function. It is possible to further combine data in order to incorporate medical knowledge, either from a patient file or from a medical atlas. This implies in particular solving complex registration problems.

A lot of effort is put into the realization of integrated hospital information systems (HIS), and more particularly related to medical imaging, into PACS development. Although a cursory glance might suggest that the issue is essentially technological, there still are many theoretical problems to solve: image coding for storage and transmission (f.ex. using wavelets), software development, design of common standards for storing and displaying data, even computer vision and artificial intelligence techniques for intelligent images data bases creation. Such data bases should allow information retrieval by semantic content: queries like “find all radiographs showing a broken arm” should be allowed.

Other applications of computer vision and artificial intelligence techniques are in medical robotics, that is the design of robots able to perform complex surgical interventions in a (more or less!) unsupervised manner.

Virtual reality equipment should also become more common, allowing physicians to interactively explore the body (and even the soul) of their patient.

6. Acknowledgements

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7. References, a very short list

There is an extremely large corpus of literature on the subject of (bio)medical imaging. Rather than trying to be exhaustive, the list below has been kept as short as possible. In particular, references to articles have been avoided.¹

7.1 Books and special issues of journals


¹ The author's major domains of interest in medical imaging have been image simplification for visual prosthesis, electron microscopy, 1D and 2D gels analysis, software environments. His present interest also includes computer vision.
be approximated by some parametrized shape, as well as for isolating regions or contours in interactive image manipulation and observation.

4.5 Classification

In the biomedical context, classification is typically supervised and done in the following manner. Training images are first segmented, then discriminative parameters are chosen that characterize the objects of interest (such as morphological measures). Covariance matrices are then computed for these measures, usually under the multivariate Gaussian assumption. Parametric discriminant functions are finally determined, allowing classification of unknown samples. These functions lead to the use of distances in parameter space (Euclidean, Mahalanobis, quadratic): an unknown sample, i.e. a point in parameter space, is classified with the closest class center according to the selected distance.

Various other approaches are also used, such as structural analysis, factorial or correspondence analysis, unsupervised classification.

4.6 3D reconstruction

3D reconstruction is certainly one of the most attractive aspects of medical imaging; it is certainly one of the most challenging as well. The possibility of visualizing 3D structures, both anatomical and functional, has brought new and extremely useful tools for diagnosis and treatment planning. Many issues are the subject of very active research; what follows concentrates on means to obtain higher-level information from the data and does not discuss the 3D image formation and acquisition itself.

The problem of matching 2D slices in order to build a 3D representation is still open. The data may come from the same device or from multiple devices, at the same time or along time. The main approaches are either to superimpose 2D pixels to create 3D voxels, or to extract and match 2D primitives from the 2D slices in order to build a 3D triangulation. Another problem is 3D segmentation, i.e. how to isolate 3D regions meaningful both in terms of morphology (e.g., tumour from CAT data) and of function (e.g., active regions in a PET image). In turn, the problems of 3D measures extraction and classification are raised.

In order to ease analysis or visualization, new types of 3D models are being introduced, either predefined parametrized shapes, or deformable models. The latter allow not only a better fit to the data, but also inherently provide segmented regions.

5. Trends in medical imaging

Many of the techniques described in this paper are now routinely used in bio-
Although 2D image segmentation has reached a certain level of maturity, 3D image segmentation is still the subject of active research; in addition, segmentation of textured images is still a major problem.

An enormous corpus of methods has been published, with three families of approaches being customarily defined (the general principles indicated below apply to both 2D and 3D images). Thresholding methods provide means for determining one (or more) grey-level thresholds, usually by analyzing the smoothed global gray-level histogram of the image. The result is thus a binary image composed of regions, hopefully with objects segregated from the background. The major drawback is the lack of local adaptability: it is rarely the case that global thresholding provides satisfactory regions. It is in general necessary to post-process the image, typically using erosion/dilation (e.g. mathematical morphology).

Edge extraction allows delineation of regions by extracting their contours. Transitions, that is regions of high variation, are first extracted using often first derivative operators (mostly Roberts or Sobel), second derivative operators (Laplacian), or adapted operators (Mero-Vassy or Canny-Deriche) that locate which part of the image match a model of an idealized contour. Contours are then obtained by locating the gradient maxima in the resulting image by means of a peak-following algorithm. The major drawback is the high sensitivity to noise; typical post-processing include thinning algorithms and gap-closing methods. Pre-processing for noise reduction is also mandatory.

Region extraction extracts parts of the image that satisfy a given uniformity criterion. Typically, it is required that for a given region the grey-level difference between a given pixel and any other one in the region be smaller than a certain value; a variation is to consider a given pixel and only its close neighbors. By principle, those methods provide closed regions and therefore closed contours, easily amenable to morphological measurements. The drawbacks are complexity of implementation, and the fact that usually many small regions are obtained. Here also post-processing is required, such as regularization of the shapes and elimination of small regions by erosion/dilation.

The most prominent usage of segmentation is to extract measures for solving classification and identification problems. Although there are as many different measures as there are particular problems, certain basic descriptors are very often used. Contour-based measures are typically the length $L$, average contrast on each side of the contour, local or average curvature. Region-based descriptors are usually based on simple values such as average luminance or color, surface $S$, perimeter $p$, elongation $p^2/S$. Moments about the center of mass are also used, for example for determining the axes of an approximating ellipse; the position of this center can help to locate objects.

Segmentation is also necessary for extracting primitive elements that will then
operate in a transformed domain, such as the well known Hough transform for
detecting straight lines or circles, can also be considered as belonging to the
family of pattern matching methods.

Fourier transforms are used for spectrally characterizing data or (linear) oper-
ators, for designing filters, for analyzing periodical structures, for sampling and
interpolation problems. Also, it is at the basis of the projection methods for re-
constructing slices (Fourier slice theorem and backprojection).

An alternative to the linear paradigm is mathematical morphology, where set
operators allow a very clean mathematical treatment of many image analysis
problems. Typical applications of mathematical morphology are particles sin-
gulation, counting, morphological parameters extraction.

4.3 Preprocessing

Preprocessing aims at eliminating systematic perturbations from the image, or
at enhancing the image for visualization and possible further processing. Typ-
ical perturbations are high-frequency acquisition noise, background luminance
variations, camera geometrical distortions, echo, etc. Preprocessing methods
are often applied in a systematic fashion on all images created by a given device
and therefore need to be fast and efficient.

Photogrammetric methods are used when the artifacts have known spatial or
luminance characteristics; examples are lookup tables for linearity correction,
dynamic range modifications, histogram equalization or interactive histogram
modifications for visualization, local or global artifact estimation and substrac-
tion. They are often performed in display memory.

Filtering methods are preferred when the spectral characteristics of the arti-
facts are known. Low-pass filters (average, Gaussian) are used for decreasing
noise, band-pass filters to eliminate periodical perturbations, high-pass filters
to enhance and sharpen edges (unsharp masking). Non-linear operators are
also employed, such as the median or out-of-range filters. Filtering is often per-
formed off-line or using specialized circuits.

Geometric corrections are required when images are geometrically distorted.
This is for example necessary for registering images from various sources. Oth-
er more complex preprocessing approaches exist, often referred to as restoration
methods.

4.4 Segmentation and measures

Segmentation aims at extracting significant primitives and regions of interest
(ROI). This is necessary either for performing measurements, that will allow
classification and identification, or for reconstruction, in order to determine the
elements that will be put into correspondence for creating a 3D representation.
Amongst the noted early works were cells classification (e.g. malignant or not) and chromosome pairing, using 2D images. Although 2D analysis still receives considerable interest, the trend is now on analyzing 3D medical information.

The generic image analysis pipeline is composed of the following steps (Fig.3):

- image acquisition, i.e., from the sensor to \( I(k, l) \) or \( I(k, l, m) \);
- preprocessing (enhancement), for example noise reduction by filtering;
- segmentation of the image into its constitutive parts, such as regions and edges;
- parameter extraction for description;
- classification, for identifying the elements present in the scene.

**Figure 3 about here**

According to this generic pipeline, some typical medical imaging applications can be decomposed as follows:

- enhancement (e.g. for contrast manipulation, pseudo-coloring):
  preprocessing \( \rightarrow \) 2D or 3D visualization by image synthesis;
- counting:
  preprocessing \( \rightarrow \) features extraction by segmentation \( \rightarrow \) number;
- classification:
  preprocessing \( \rightarrow \) features extraction \( \rightarrow \) morphological parameters \( \rightarrow \) decision;
- 3D imaging and diagnosis (e.g. for radiotherapy, surgery):
  2D or 3D acquisition \( \rightarrow \) segmentation \( \rightarrow \) approximation \( \rightarrow \) 3D reconstruction \( \rightarrow \) visualization;
- data coding and storage (e.g. for PACS):
  2D or 3D acquisition \( \rightarrow \) (preprocessing) \( \rightarrow \) approximation.

**4.2 Linear theory**

Linear systems theory is the basic paradigm for a large number of methods. Having a 2D or 3D discrete input image \( I(x, y) \), the effect of applying a discrete linear operator of known impulse response (transfer function) \( g \) yields \( I_y = I_x \ast g \), where \( \ast \) is the discrete convolution product. Although not many algorithms are linear, it is often useful to study their behavior using the linear formalism. Concretely, the main applications of the convolution product are for preprocessing and edges extraction.

Correlation, which determines the degree of correspondence between a pattern and an image, is used for isolating a priori known shapes. The pattern matching operation is normally implemented in the image domain. Other algorithms that
Alternatively, it is possible to compare the objects between themselves, in order to eliminate the parts that will be occluded. Although more complex than the former, the basic advantage of these object space methods is that they do not imply recomputing visibility information if the vantage point is modified. Typical algorithms are visible line determination, depth sort, area subdivision, radiosity.

### 3.5 Lighting

Finally, what is the effect of adding light sources? Although not mandatory, this provides the means of adding shading effect on the visualized objects and therefore significantly increase the realism of the result. If the scene is described by triangular planar facets, the most common methods are constant, Gouraud or Phong shading.

With constant shading, each facet has the same $I$ value, determined using the direction of the facet normal and the illumination equation. Although very simple, the results are not very satisfactory; in particular, the transitions between facets are clearly visible due to the Mach effect (enhanced perception of sharp transitions). Gouraud shading determines one “true” scalar $I$ per facet vertex, then linearly interpolates these scalar values. This method is often implemented in hardware; its major drawback is a poor rendering of specular reflections. Phong shading adds one more level of precision (and complexity) by vector interpolation over the whole facet of the local 3D normals to each facet vertex, and by computation of $I$ at every point by using the illumination equation.

Various methods are being developed to increase the realism of the result, in particular by adding textural effects. This is achieved either by projecting stored patterns on the surface (texture mapping) or by locally modifying this surface (bump mapping). Stochastic models are often used, such as fractal or particles ones.

### 4. 2D and 3D image analysis

Image analysis has been active since the 1960's. Although the availability of powerful computers certainly boosted research, the lack of these was never considered as a real hindrance. The 1960's were the decade of early hopes, when it was thought that realizing a computer vision system would be easy. The 1970's were the years of rather ad-hoc, engineering type of approaches. The 1980's have seen the advent of computational vision and the establishment of strong links with human neurophysiology. The trend for the 1990's seems to be cognition, with a marked interest towards cognitive psychology.

#### 4.1 Medical imaging analysis pipelines

Since its inception, image analysis was concerned with medical applications.
3.2 Geometrical models

Geometric models are the basic tokens that the visualization pipeline will have to process. In the context of medical imaging, the most commonly used models are the simple voxel and the 3D polygonal planar patch. The voxels are obtained either directly with an appropriate acquisition device, or indirectly by superimposing the 2D slices. The 3D polygonal planar patches are usually triangular; 3D triangulation is typically based on the registration of polygonal contours approximations from the successive slices. Although this approximation process might be difficult, it allows an important reduction of the amount of data, additional possibilities such as volumetric and mass measurements, and more efficient visualization and animation schemes.

Other approximation principles are the subject of current research, such as using spline patches or deformable models ("snakes" or "inflatable balloons") that modify themselves in order to adapt to some key data features.

3.3 Transformations

The purpose of the geometric transformations is to compose the 3D scene that will have to be visualized, starting from 3D object models. Typical transformations are rotations, translations and scaling, implemented using the formalism of homogeneous coordinates. They operate on the object models, which are thus instantiated at a specific position, with a specific angle in space and a given size.

After having composed a scene, the display transformations project this 3D scene \((x, y, z)\) onto the 2D display viewport \((k, l)\); this projection is also implemented using homogeneous transformations. The removal of object parts that fall outside the viewport is performed using clipping algorithms, such as Cohen-Sutherland's one.

3.4 Visible surface determination

Which are the pixels, lines or surfaces of the object that are visible from the point of view, that is the center of projection of the virtual camera? Visible surface determination methods answer this question, by determining the elements that are not occluded by others.

The generic principle of image space methods is to determine, for each pixel \(I(k, l)\) of the projection plane, which is the closest object along the 3D line (ray) defined by the center of projection and \((k, l)\). The intersection of this line with the object yields the color value for \(I(k, l)\). Typical methods that belong to this family are the very common z-buffer algorithm, the scan-line algorithms, or the ray tracing approach. Most dedicated graphical workstations are designed to incorporate a z-buffer memory, which allow easy implementation of the z-buffer algorithm.
3. **3D image synthesis**

Although some early work on interactive environments has been accomplished in the 1950's, and Sutherland developed his Sketchpad in the 1960's, the “big leap forward” really occurred in synchrony with the progresses in hardware development, i.e. starting in the late 1970's. The 1980's were the decade of realism and natural models, whereas it seems that the 1990's could be the decade of virtual reality.

### 3.1 Visualization pipeline

What follows concerns tridimensional data visualization; the problems encountered with 2D data are a simple subset of the 3D methods and are not described here.

The basic paradigm of 3D synthesis is the virtual camera. The various elements to be visualized are put together in order to compose a “scene”. A snapshot of this scene is made by projecting it on a plane, either along a projection direction, or using a center of projection (Fig.1).

**Figure 1 about here**

Synthesizing a 3D image roughly involves the following sequence of operations, that compose the visualization pipeline (Fig.2):

- modelling three-dimensional objects in their own coordinates system, i.e., describing their morphology, attributes, and sometimes functionality;
- composing a scene by instancing these objects at various locations within a common reference frame \((x, y, z)\);
- lighting the scene, which involves modelling light sources and illumination mechanisms;
- determining the reflection and shading effects of these sources on object surfaces;
- removing invisible areas of the scene and projecting visible parts onto \(I(k, l)\);
- displaying \(I(k, l)\), which means taking into account display as well as human visual system characteristics.

**Figure 2 about here**

There is a certain freedom in the ordering of the various operations. Also, various algorithms cleverly combine several of these above stages.
pulations, the more perceptually significant \{hue, lightness, saturation\} HLS space is preferred.

Another aspect of light is the modeling of reflections. Phong's traditional illumination equation models the value $I(k, l)$ of the 2D image pixel corresponding to a 3D scene point $P(x, y, z)$ as a weighted sum of three components: ambient light, diffuse reflection and specular reflection. This equation is for example important for the last stage of the visualization pipeline, that is the rendering of the effect of light sources. It is worth emphasizing the fact that Phong's equation is only a model and that most of its parameters are empirically chosen in order to provide a given visual effect.

2.3 Equipment

Medical imaging devices usually provide 2D data (pixels); after having obtained sets of 2D data, such as slices or image sequences, they are often combined into a 3D representation. More recent devices now allow direct acquisition of 3D data (voxels). The data can then either be visualized, using 3D image synthesis methods, or analyzed, using 2D or 3D image analysis techniques.

Typical transmission based morphological measurements are made using digital radiography (2D data) or axial tomography - CAT (2D data, often combined into 3D volumetric information, or 3D data). Emission based morphological and functional measurements (nuclear medicine) are performed by angiography or scintigraphy (2D), or using the more recent positron emission tomography - PET (2D or 3D). There are many other medical imaging techniques that are more and more routinely employed, such as nuclear magnetic resonance - NMR (2D → 3D), echography (2D → 3D), thermography, retinography, Moiré interferometry, etc.

More general purpose type of devices are needed in a medical imaging laboratory. Regarding standard acquisition and reproduction devices (scanner, camera, printer), the trend is now to use color. For processing, dedicated workstations are usually based on reduced instruction set chips - RISC, and parallel processing becomes feasible. State of the art display technology now implies "true" color (8 bits depth for R, G, B each), large flicker free screens (> 1M pixels, refresh rate > 66 Hz non interleaved), and sometimes stereoscopic devices. Mass storage using juke-boxes of optical discs becomes common, especially in view of Picture Archiving And Coding Systems (PACS). Various software standards are also emerging, such as PHIGS+ (Programmer’s hierarchical interactive graphics system) for image synthesis, Motif and X11 for interface design and communication protocol. The use of X11 allows to have separate CPUs for processing and for display control; in other words, a low cost workstation can be used for the interaction with the physician while at the same time the CPU intensive processing with all the computations and control of this interaction is done on another, more powerful computer.
tive, thus enabling earlier diagnosis than with conventional exploratory meth-
ods. A consequence is the ability of providing more finely tuned medical treat-
ment, for example lower doses in radiation therapy. Precision, repeatability
and consequently objectivity are also important.

The use of image synthesis techniques in medicine is mostly for 2D and 3D vi-
sualization purposes. Typical applications are in diagnosis or planning, for ex-
ample for surgery or radiotherapy. Graphical methods can also be employed for
simulation, typically by means of computer animation techniques.

The history of image analysis in medicine is older than the one of image synthe-
sis (1960's rather than 1980's). The early works were concerned with applica-
tions such as counting, coding for image compression and storage, or morpho-
logical parameters extraction (hence classification). More recently, the advent
of new imaging technologies has lead to 3D reconstruction methods, either from
slice data or from image time sequences. Extraction of 3D morphological struc-
tures is a very active research area. Complex computer vision techniques are
also being used in domains such as medical robotics.

2. Common concepts

Overlaps between image synthesis and analysis are numerous; this section pre-
sents some of these common concepts in the context of medical imaging.

2.1 Human perception

The common basis for synthesis and analysis lies in the way humans see things.
Computer graphics is obviously intimately concerned with perception. The
physics of display certainly has influence over what is observed, but what really
matters is the internal representation to which a given image refers and which
it seeks to recreate in the user. In the case of a physician establishing a diagno-
sis on the basis of a 3D rendered image, using knowledge from human percep-
tion could help design analysis and synthesis algorithms that would convey a
message more forcefully.

In a different manner, perception is also important for image analysis, as as-
psects of human vision are often used as paradigms for the development of the-
ories and algorithms.

2.2 Light

It has been known since the past century that human perception of color in-
volves three quantities, or degrees of freedom. For screen displays, it is custom-
ary to use the {red, green, blue} RGB additive space, while the {cyan, magenta,
yellow} CMY subtractive primaries are utilized for hardcopy color printers.
When user interaction is required, for example in the case of color tables mani-
1. Introduction

1.1 Digital image

In what follows, an image is considered to be a function \( (k, l) \rightarrow I(k, l) \), where \((k, l)\) are coordinates on a two-dimensional grid, and where \(I\) is a measure such as brightness. The grid is generally rectangular, although the use of hexagonal grids is gaining interest. In a more general manner, images can be characterized by a support of dimension higher than two, as is the case with a sequence of images \( I(k, l, t) \) or with volumetric data \( I(k, l, m) \), where \(t\) is time and \(m\) the third dimension.

For a given grid, the values for \(I\) can be binary (0,1) or grey-level values (typically 8 bit, from 0 to 255). There can also be more than one measure at each location; this is what happens when spectral information is taken into account: \(I_\lambda(k, l)\), where \(\lambda\) is wavelength. This spectral information is usually reduced to a triple such as \(\{I_{\text{red}}(k, l), I_{\text{green}}(k, l), I_{\text{blue}}(k, l)\}\). In all these situations, the basic structure of information is an array of quantized numerical values, the basic element of information being a 2D picture element (pixel) or 3D volumetric element (voxel).

1.2 Image synthesis versus image analysis

Image synthesis (or computer graphics) consists in determining a value for each of these pixels, the end product being a 2D or 3D image with (hopefully) some semantic and/or artistic content; in other terms, image synthesis does a parameters to \(I_\lambda(k, l, t, m)\) transformation. Image synthesis has always been closely associated with human-computer interaction. The full exploitation of the computer as a medium for image synthesis is only achieved in a dynamic, interactive environment.

Conversely, image analysis does a \(I_\lambda(k, l, t, m)\) to parameters transformation, starting with image(s) for which each element has a known value. It is customary to subdivide the domain into image processing, image analysis in the strict sense, and computer vision. Image processing consists in transforming one image into another image, often with the same support; the purpose is typically to eliminate or enhance some features. Image analysis goes one step further by extracting parameters and analyzing them; classical domains of application are medical imaging or industrial robotics. Finally, computer vision attempts to provide a symbolic description of an image or scene.

1.3 Domains of application in medicine

The motivations for using digital imagery methods in medicine are various. Foremost comes the possibility of exploring new imaging modalities, leading to new anatomical or functional insights. Those methods are usually fairly sensi-
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Abstract

This article wishes to present a unified overview of the various aspects of 2D and 3D digital imaging methods for medical applications. Rather than specifically addressing a particular issue, the emphasis is put on a general description of the image synthesis and image analysis pipelines. Since such paper cannot be really comprehensive, it has deliberately been kept short and descriptive.

The goals of image synthesis and analysis are first recalled, in particular for (bio)medical applications. Image synthesis and analysis share many common concepts, amongst which some are specifically described. A general view of the visualization pipeline summarizes the issues that have to be addressed when displaying image data. Conversely, when analyzing such data by means of image analysis, the various processing pipelines share common methodological approaches; the major elements of these approaches are presented. Finally, current trends in medical imaging are indicated.

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