ADVANCES OF MEDICAL VISUALISATION

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Abstract: In the paper the review of most commonly used techniques of medical visualisation is presented. Both 2D and 3D medical visualisation problems are illustrated with examples of our research. Especially remote visualisation (teleradiology) with telematics tools is taken into consideration. This leads to underline the role of networking in telediagnosis. The importance of application of powerful computers and sophisticated software, supported by TASK, for medical visualisation is emphasised. Some results of medical data and information visualisation obtained in our Department are presented.

1. Introduction

Visualisation links the two most powerful information processing systems known — the human mind and the modern computer. This is a process, that transforms data, information and knowledge into a visual form exploiting people's natural strengths in rapid visual pattern recognition. Effective visual interfaces enable to observe, manipulate, search, navigate, explore, filter, discover, understand and interact with large volumes of data to discover hidden patterns [1][2]. This advantage of data and information visualisation is extremely important in medical applications. The proper representation of data to a professional doctor, partly or fully data processing with general image processing algorithms, or special visualisation techniques is crucial for a proper diagnose.

In modern, increasingly information-rich society the visualisation research and development has fundamentally changed the way people present and understand large complexes of data sets. Much previous research in visualisation arose from the scientific community's efforts to cope with the huge volumes of scientific data collected by scientific instruments or generated by massive supercomputer simulations. Information visualisation combines aspects of human-computer interfaces, data mining, imaging and graphics.

Tailoring visualisation systems based on human capabilities of perception and information processing poses another challenge. We need to understand better how human beings interact with information, how it is perceived visually and non-visually, how the mind works when searching for both known and unknown information, and how the mind solves problems. Recently also the Web has provided a flexible means for linking applications, data, information, and users.

The seamlessly interlink associated data and couple visual representations with this data creates an opportunity for new approaches to visualisation. We use the term „Web-based information visualisation" to describe visualisation applications that use the Web as an information source, a delivery mechanism for visualisation, or both.

A good understanding of anatomical structure is crucial for diagnosis and therapy planning in order to comprehend complex anatomical structures and their interrelationships. A 2D/3D data set represents a vast amount of information, of which only a minor fraction is of real interest — users usually want to have the ability to visualise specific tissues or organs, since in general mainly tissue boundaries are of the highest interest. A reliable segmentation (classification) is thus an important method for medical data visualisation [3][4]. New developments in 2D and in 3D volume acquisitions, such as spiral CT (Computed Tomography) scanning, faster and better pulse sequences for MRI (Magnetic Resonance Imaging) and improved functional imaging using PET (Positron Emission Tomography), SPECT (Single-Photon Emission Computed Tomograpy), EEG (Electroencephalography), MEG (Magnetoencephalography), fMRI (functional Magnetic Resonance Imaging) and MRS (Magnetic Resonance Spectroscopy) are creating a rapidly increasing demand for integrated visualisation [5]. Here, even more than for single modality images, the problem of mentally reconstructing a picture comprising the information provided by the various modalities appears. Special attention must also be put on visualisation in EIT and termography. Both techniques of data acquisition require sophisticated reconstruction algorithms and visualisation techniques which are, in the case of 3D EIT, based on special voxel type (e.g., 4-sides elements). Visualisation of three dimensional data reconstructed from cross-sectional slides, visualisation of anatomical data sets (often GB of data — e.g., Visual Human Project; male data set 15GB, female data set 40 GB), presentation of absolute colour values for stored data at different hardware are also important problems for fast and accurate medical visualisation methods [6].

2. Visualisation and visualisation techniques

Visualisation — the computer science and mathematical techniques that allow users to take their data from the information space in which it currently dwells to the visualisation space that graphically represents this data in a form that is meaningful in a visual context [7].

Prior to using visualisation techniques it is very useful to apply various data manipulation tricks to prepare the data for the visualisation process. The following techniques are usually useful:

1. Image algebra operations,

2. Filters,

3. Interpolations,

4. Geometrical operations.

After data preprocessing we can visualise our information. The following techniques are usually used for visualization purposes:

1. Edges — finding boundaries of data,
2. Contours and isolines,
3. Slices and cross-sections,
4. Colour Lookup Tables — CLUTs,
5. Image processing,
6. Glyphs,
7. Vector fields,
8. Plots,
9. Animations,
10. Probes and interaction.

2.1. Exteriors and edges

It is often necessary to know the outer reaches of both data and the data space that it inhibits.

By definition, the data boundary is a set that inclusively contains the data itself. When visualised, the data boundaries manifest themselves as visible edges, boundaries and surfaces. In other words the data itself has minimum and maximum values in each of the dimensions the analyst chooses to represent. These minima and maxima are the data boundaries. By contrast, the data space extents are the limits imposed on the boundaries for a coordinate system in which the data set has been placed. Ideally, the data space extents are metasets for the data boundaries, but this is not necessarily the case. When forced into graphical context, data space extents can be rendered as edges, walls or surfaces. Therefore the data space extents can be thought of as the minima and maxima at the coordinate system containing the data.

In medical applications extraction of edges is very important for definition of body boundaries in an image. Different algorithms which allow to create boundary usually can generate also vector line (boundary line). This vector line is often stored as an overlay of the image.

2.2. Contours, isolines and isosurfaces

In traditional 2D visualization contours are used for visualising bins and their relationship to each other. An algorithm produces potential boundary lines or isolines, between data that falls on either side of a selected data value. Contours are used to group data values according to a specified class. This means that these operations could be used for image segmentation purposes. Contours-based image segmentation algorithms allow for manual or automatic classification of bones, organs and tissues in medical images. These techniques help medical doctors to specify a proper diagnose and can even automatically distinguish damaged areas in a body. Recently such techniques have been used e.g., for breast cancer and microcalcification recognition from breast radiological images.

2.3. Slices and cross-sections

Detecting patterns and structure using contouring and isosurfaces in a very complex volume, a volume composed of a very high resolution data, might be difficult and inefficient. Some volumetric data, such as medical MRI scans, may reveal more structure when the volume is dissected with arbitrary, two dimensional slices (fig. 1). Volumetric data are common today in the case of medical 3D visualisation [8][9]. Further some more information about this technique is presented.

Figure 1. 3D reconstruction of a head from 2D images [from IDL presentation example].

2.4. Colours, Lookup Tables

One of the visual cues that aid humans as they navigate through their environment is the ability to detect and discern individual wavelengths of visible light. This information is represented in our brains as colour and is passed off to different areas of our brain for further processing. The human ability to detect small differences in the wavelengths of visible light emitted or reflected by an object is probably an evolutionary survival skill — it is, after all, easier to spot the bright orange tiger against the dark brown grass if the eye can discern the difference between the wavelengths reflected off these two objects. Because we evolved with such a fine sensitivity to discriminate between two different wavelengths of light, colour is one of the best cues available in information visualisation.

Digital data values in a data set can be assigned colours in a variety of ways, but one of the most common is a specialised form of binning. Specific data values or specific ranges of data values are assigned an ordinal number. This number is used as an index into a list of colours in a colour lookup table (LUT). The colour values at each index in the LUT are represented by a distribution of intensities on each of the red, green and blue channels. The intensities in each of the RGB channels are restricted by computer's graphics hardware.

The number of colour bits or colour depth, assigned to computer's graphics hardware, is the maximum limit on the colour values that can be placed in software's LUT. The relationship between this maximum number of colours available and the colour depth of hardware is simple for bits depth 24 or less: 2n, where n is the number of bits of colour depth. Sometimes computer hardware allow to use 32 bit colour system. This means that 8 extra bits (alpha channel, overlay plane) are used to store additional information for labels, annotations, etc.

In medical applications images are usually stored with the colour depth 8, 10 and 12 bits. This means that values are encoded in computer with 8-bit or 16-bit field width. Unused bits in 16-bit long field store additional information (e.g., overlay data). This means that each time an application reads data from a file it has to perform logical and mathematical operation to: 1. extract image bits, 2. create proper pixel value. Such operations need a lot of clock cycles, so they are time consuming in case of slow computers. The simplest solution is to use fast computers to perform high efficiency. Another problem in medical colour visualisation is the method of converting values into colours. It is extremely important that each time the original medical image is presented, it has the same colours on the video display terminal. To solve such problems some standards of medical image storing were defined. As an example DICOM — Digital Imaging and Communication in Medicine — defines special modules, which are describing methods of proper definition of colour (grey-scale) LUT and conversion method (linear and non-linear) between measured values (from modality) and displayed colours.

2.5. Image processing

A subfield of information visualisation is image processing. In this usage, an „image" is a 2D data field that deals exclusively with two dimensional imagery obtained from either sensors or from generated information. Image processing refers to the manipulation of an image as data in order to extract as much information as possible.

Image processing, however, is not just tinkering with the colour maps. It also involves manipulation of an image as a data set: cropping, rotation, additions and subtractions of two or more images, bitwise ands and ors of two or more images, and so on. In addition to these relatively simple mathematical tricks, the field of image processing includes far more advanced techniques, such as:

- filtering — removal of noise and missing data from an image,
- edge detection — locating edges defined as the border between two sharply contrasting regions,
- Fast Fourier Transforms — FFT — translation of data from a spatial domain to frequency domain,
- histogramming — creation of a histogram chart showing the number of data values falling into each LUT index position.

2.6. Glyphs

Glyphs are small 3D graphic objects which represent one or more data values at a single location in space. They are very useful to interpret a large quantity of information at a single glance.

2.7. Vector fields

Vector field is often used to denote data that not only has a position in space, but one or more additional components representing for example energy, speed, etc.

2.8. Animation

Animation is processing of rapid images of the same spatial scene at different time (e.g., USG) or displaying of the same scene viewed at different positions (e.g., 3D CT). Very often animation is used to show motion in medical applications (e.g., heart beat). Motion, besides of colour, is the most important visual cue available to researchers utilising information visualisation.

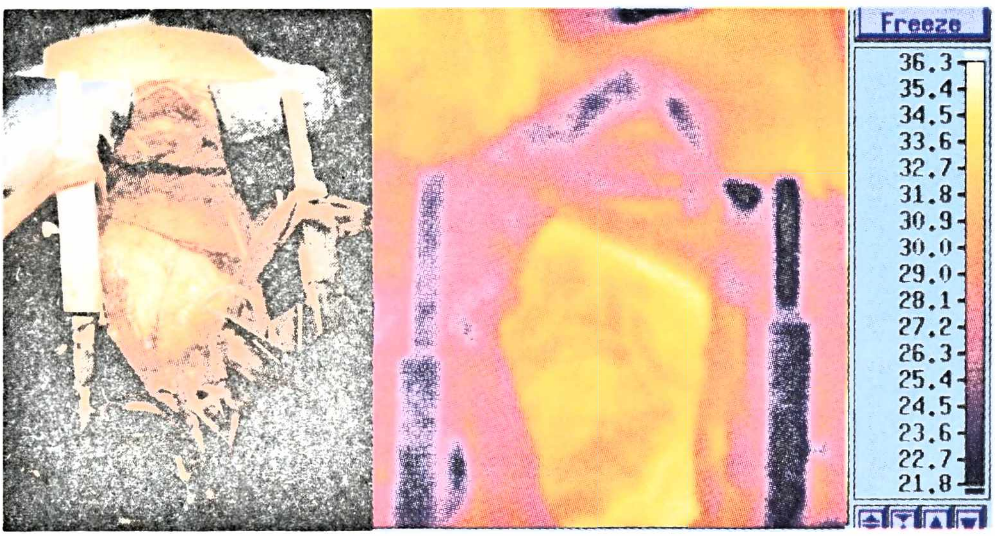

Figure 2. *Left: Photo of a heart during operation; Right: part of the infrared movie taken during this same operation [8]. Such infrared movie allows to examine bypass during operation.*

2.9. Probes

Very often in data visualisation applications it is important that a researcher has an opportunity to interact with his data. A simple mode of interaction would be using a probe, a geometric construct that could be inserted into a scene and moved. When the specified probe collides with a data location it generates an event. The event handling is determined by the user (often it is only a printout of a value of a data point or its location).

3. 3D visualisation

Three dimensional visualisation in medicine becomes more and more popular. The present solutions are based on generation of 3D objects from cross-sectional slices or on three dimensional structures of basic, identical elements, called voxels (fig. 3). In MRI or CT voxels are usually regular cubic elements, with the exception of the height element which depends on frequency of slice acquisition (the height of a voxel is usually a few times greater than its other sides) [10].

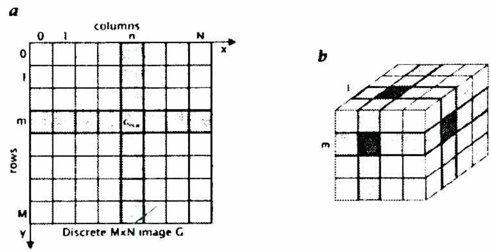

***Figure 3.** a. Piksels matrix in 2D image, b. Voxels in 3D visualisation.*

Information with a spatial component collected as a volume is typically represented as discrete points in 3D-space. Volumes of data can also be generated, rather that collected. Alternatively, data set that is only two dimensional but also has a time component is often represented as a series of 2D slices stacked one on top of another. These types of views into data are called volumetric renderings and they pose a number of problems. Most notably, if data set is represented as a solid volume of points, how to see the internal structure?

True three-dimensional imaging is becoming more accessible with the continued development of instrumentation. Just as the pixel is the unit of brightness measurement for a two-dimensional image, the voxel (volume element, the three-dimensional analog of the pixel or picture element) is the unit for three-dimensional imaging. And just as processing and analysis is much simpler if the pixels are squares, so the use of cubic vowels is preferred for three dimensions, although it is not as often achieved as the simplest 3D structure is [9].

There are several basic approaches to volume imaging in medicine [11][12]. One example is 3D imaging by tomographic reconstruction (fig. 4). This is perhaps the premier method for measuring the density and even in some cases the elemental composition of solid specimens. It can produce a set of cubic voxels. This is not the only or even the most common way that tomography is presently used. Most medical and industrial applications produce one or a series of two-dimensional section planes, which are spaced farther apart than the pixel resolution within the plane.

Tomography in medicine can be performed using a variety of different signals, including ultrasound, magnetic resonance, conventional X-rays, gamma rays, neutron beams and electron microscopy as well as other, even less familiar methods. The resolution may vary from centimeters (most conventional medical scans) to millimeters. The same basic presentation tools are available regardless of the imaging modality or the dimensional scale.

The most important variable in tomographic imaging, as for all of the other 3D methods discussed here, is whether the data set is planes of pixels or true voxels. It is possible to set up an array of cubic voxels, collect projection data from a series of views in three dimensions and solve (either algebraically or by backprojection) for the density of each voxel. However the most common way to perform tomography is to define one plane at a time as an array of square pixels, collect a series of views in two dimensions, solve for the densities in that plane and then proceed to the next plane. When used in this way, tomography shares many similarities (and problems) with other essentially two-dimensional imaging methods that we will collectively define as serial imaging or serial section techniques [13][14].

A radiologist viewing an array of such images is expected to combine them in the mind to „see" the three-dimensional structures present. (This process is aided enormously by the fact that the radiologist already knows what the structure is and is generally looking for things that differ from the familiar.) Only a few current-generation systems use the techniques discussed here to present three-dimensional views directly [15].

Because cross-sectional based 3D volume generation method is mainly used in medical 3D visualization it is worth to say a few words more about it [9].

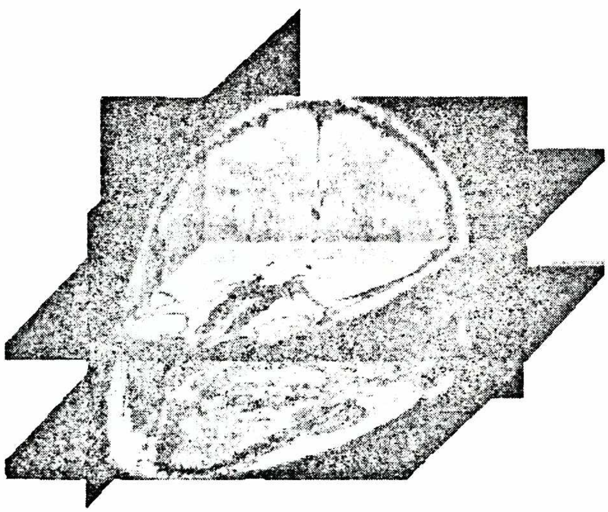

Figure 4. Generation of 3D volume from MRI cross-sectional images.

Since most 3D image data sets are actually stored as a series of 2D images, it is very easy to access any of the individual image planes, usually called slices. Playing the series of slices back in order to create an animation or „movie" is perhaps the most common tool available to let the user view the data. It is often quite effective in letting the viewer perform the 3D integration and as it recapitulates the way the images may have been acquired (but with a much compressed time base); most viewers can understand images presented in this way [16].

A simple user interface needs only to allow the viewer to vary the speed of the animation, change direction or stop at a chosen slice, for example.

One problem with presenting the original images as slices of the data is that the orientation of some features in the three-dimensional structure may not show up very well in the slices. It is useful to be able to change the orientation of the slices to look at any plane through the data, either in still or animated playback. This change in orientation is quite easy to do as long as the orientation of the slices is parallel to the x, y, or z axes in a data set. If the depth direction is understood as the z axis, then the x and y axes are the horizontal and vertical edges of the individual images. If the data are stored as discrete voxels, then accessing the data to form an image on planes parallel to these directions is just a matter of calculating the addresses of voxels using offsets to the start of each row and column in the array. This addressing can be done at real-time speeds if the data are held in memory, but is somewhat slower if the data are stored on a disk drive, because the voxels that are adjacent along scan lines in the original slice images are stored contiguously on disk and can be read as a group in a single pass [17] [18]. However, when a different orientation is required the voxels must be located at widely separated places in the file and it takes time to move the reading head and wait for the disk to rotate.

It is actually not too common to perform 3 directional resectioning with MRI data (or most of other kinds of medical images) because the spacing of the planes is greater than the resolution in the plane and the result is a visible loss of resolution in one direction in the resectioned slices due to interpolation in the z direction. The alternative to interpolation is to extend the voxels in space: in most cases, this is even more distinctive to the eye. Interpolation between planes of pixels can be done linearly or using higher order fits to more than two planes or more than just the two pixels immediately above and below [21]. But while interpolation produces a visually acceptable image it can ignore real structure or create apparent structure.

Recently 3D multimodality visualisation of medical data has been taken into consideration. Some results of projects (e.g., COVIRA — Computer Vision in Radiology) propose new method for multimodality images coregistration to obtain common presentation of different organs in this same coordination system (bones from CT, soft tissues from MRI, functional activity from fMRI or PET, etc.,) [10][19][20][22].

After generation of 3D medical volume 3D segmentation algorithms are often used to visualise particular objects from volume (e.g., brain).

Special kind of information visualisation is performed in ElectroImpedance Tomography — EIT.

In EIT — basic methods of image reconstruction are based on Finite Element Method (or Boundary Element Method) so 3D image is constructed from 4-sides elements. As a matter of fact also in these applications two kinds of 3D image generation exist: from 2D images and real 3D data acquisition. Up to our knowledge we are using for the first time a real 3D EIT breast data acquisition and visualisation [23][24][25]. Such operations are more reliable from diagnostic point of view, but are much more complicated in the case of an object reconstruction and visualisation.

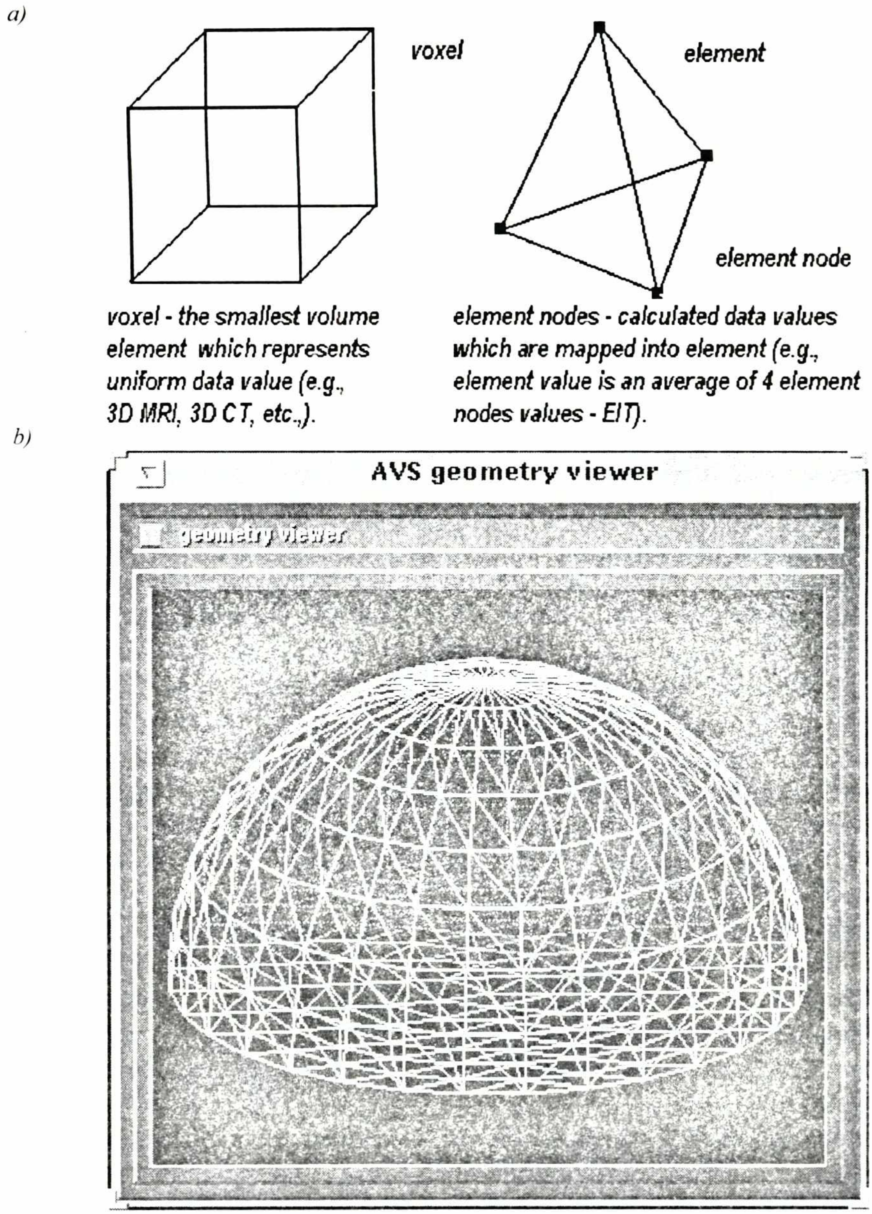

***Figure 5.** a) Voxel and element role in visualisation, b) Finite element mesh of defined geometry of breast model.*

In EIT element value of the object depends on calculated values in element nodes (fig. 5). This is the main difference between voxel-based visualisation where each voxel represents uniform data value and is often treated as a point value and element-based visualisation where element value depends on values in nodes.

Element value in EIT is usually average value of all nodes of the given element. Sometimes different methods of interpolation are used to define element value. Such methods divide an element into a set of smaller elements where each smaller element has different value based on a node value. As a result we can obtain impedance distribution in a volume, which can be a source of information as structural data or more often as functional data (differential mode) (fig. 6 and 7).

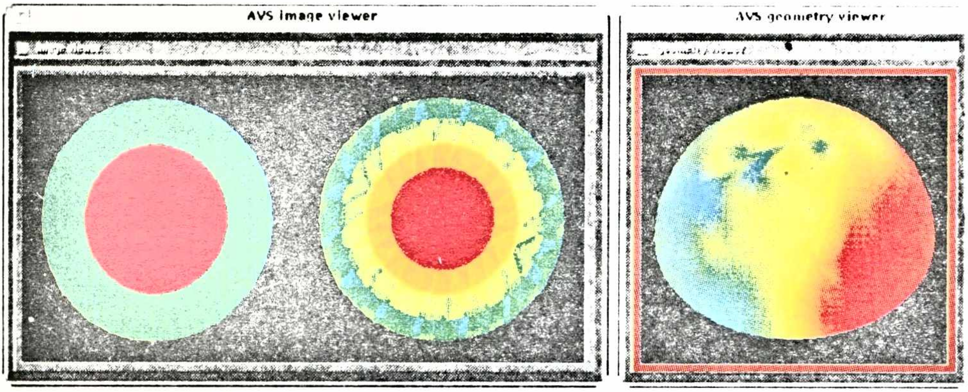

Figure 6. *Cross-sectional and surface presentation of reconstructed impedance values of defined 3D geometry in EIT*

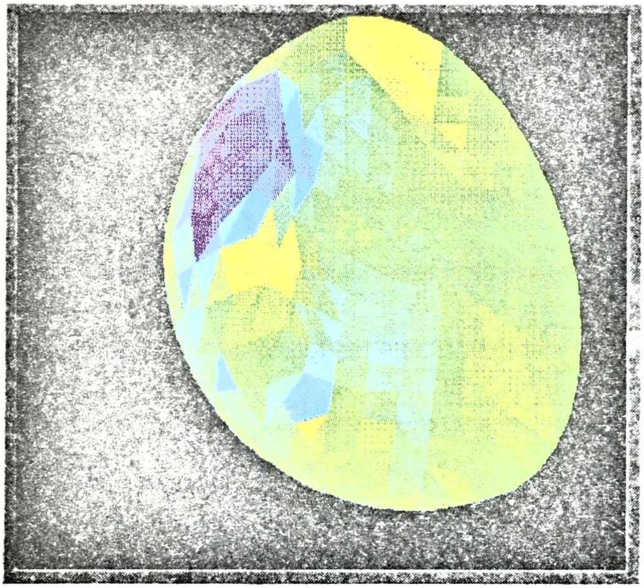

Figure 7. *Presentation of reconstructed impedance values of defined 3D geometry in differential EIT (measured activity in blue colours, green colours — background)*

4. Remote diagnosis
Picture archiving and communication systems (PACS)

Remote diagnosis is usually performed using videoconferencing systems with support from a professional, high resolution visualisation system. Such visualisation system needs excellent networking which usually relies on fast medical network and efficient network protocols. The difficulty of setting up a distributed PACS resides in the complex task of distributing the information to the users in multiple locations. This requires appropriate usage of high performance networks (some medical images are huge e.g., in digital mammography, so fast remote visualisation needs effective throughput). High speed networks can provide very high data throughput, but wide distribution of large amounts of data cannot rely on a single network. Multi-tiered networks combining different networks with different bandwidths are necessary [26].

Most groups doing PACS related work encountered the problem of acquiring images and image related data from different manufacturer's equipment [27]. A solution for this problem is widely adopted today Digital Image Communication (DICOM) standard.

This new international standard was created by the American College of Radiology (ACR) and National Electrical Manufacturers Association (NEMA) with co-operation with international organisations and medical companies [28].

The goals of DICOM standard are:

- to promote communication of digital image information, regardless of device manufacturer,
- to facilitate the development and expansion of picture archiving and communication systems (PACS) that can also interface with other systems of hospital information, e.g. HL7 standard,
- to allow the creation of diagnostic information data bases that can be interrogated by a wide variety of devices distributed geographically.

Data exchange with DICOM standard is based on client/server solution (network) or on traditional data exchange with media (e.g., CD-ROM, MO disks). In both solutions there is a need to define:

1. data representation (data format),
2. services (send, receive, store, read, etc.).

According to DICOM, two connected computers (devices, workstations,etc.) have to define the role (fig. 8) they will play in communication process (server — „Service class provider", client — „Service class user") and basic syntax of data transfer (e.g., data stream encoding — big endian, little endian, JPEG). Using media data writer has to define DICOMDIR file with references to DICOM files which describe this same study [29].

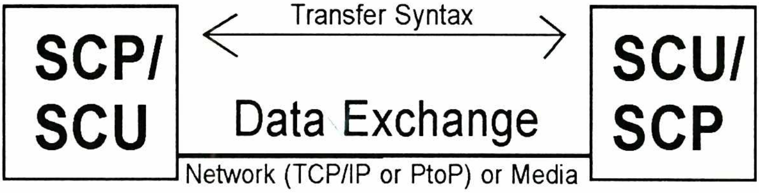

Figure 8. Data exchange model according to DICOM standard.

Full description of working with data in DICOM is given by SERVICE CLASS. Subset of service class is Service-Object Pair Class, which defines relations between data (object) set and services for that data set (fig. 9).

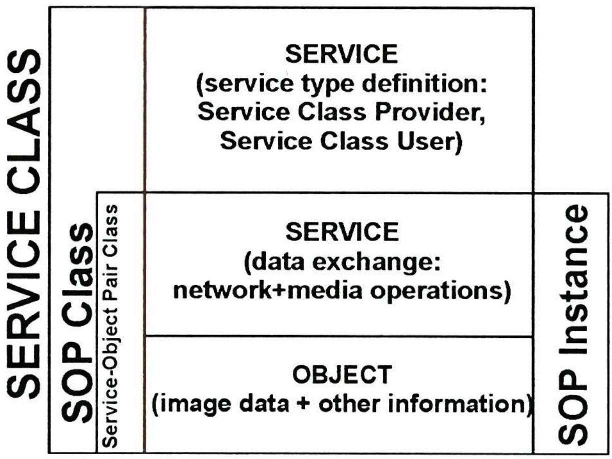

Figure 9. Service class definition in DICOM.

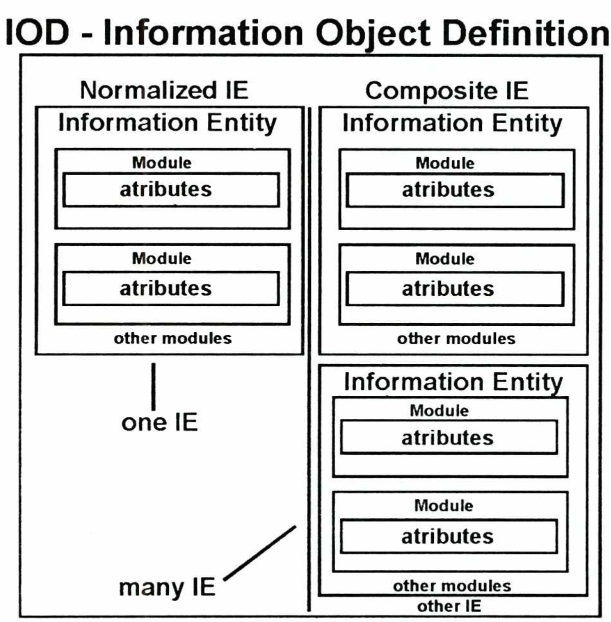

Figure 10. Information Object Class definition.

All data objects (patient data, study data, image data, etc.) are defined by IOD — Information Object Definition. IOD groups data in special thematical Information Entities and modules. Each module is defined by a set of attributes (fig. 10). SOP defines possible services for IOD and IE in either the composite group (C-XXXX) or the normalised group (N-XXXX). The following Service Elements are available: C-STORE, C-FIND, C-MOVE, C-GET, C-CANCEL, C-ECHO, N-GET, N-SET, N-ACTION, N-CREATE, N-DELETE and N-EVENT-REPORT. The semantics of the Service Elements depend on the Service Class and SOP Class in which they are used. Media-related Service Elements M-WRITE, M-READ, M-DELETE, M-INQUIRE-FILE-SET and M-INQUIRE-FILE define primitive functions for manipulation with file sets.

Proper implementation of IOD (Information Object Instance) and services allow to exchange medical data according to DICOM. DICOM based PACS are commonly offered from various medical companies. Such systems enriched with special data storage units (usually data production at Radiology Department is about 1-5 GB a day, so the archiving system must be very large and secure) and security system allow to perform local and fast, remote diagnosis based on image presentation.

5. Software

Visualisation in medicine is possible thanks to professional software. At our Department we currently use our own visualisation software (e.g., see fig. 11) as well as commercial software (TASK support).

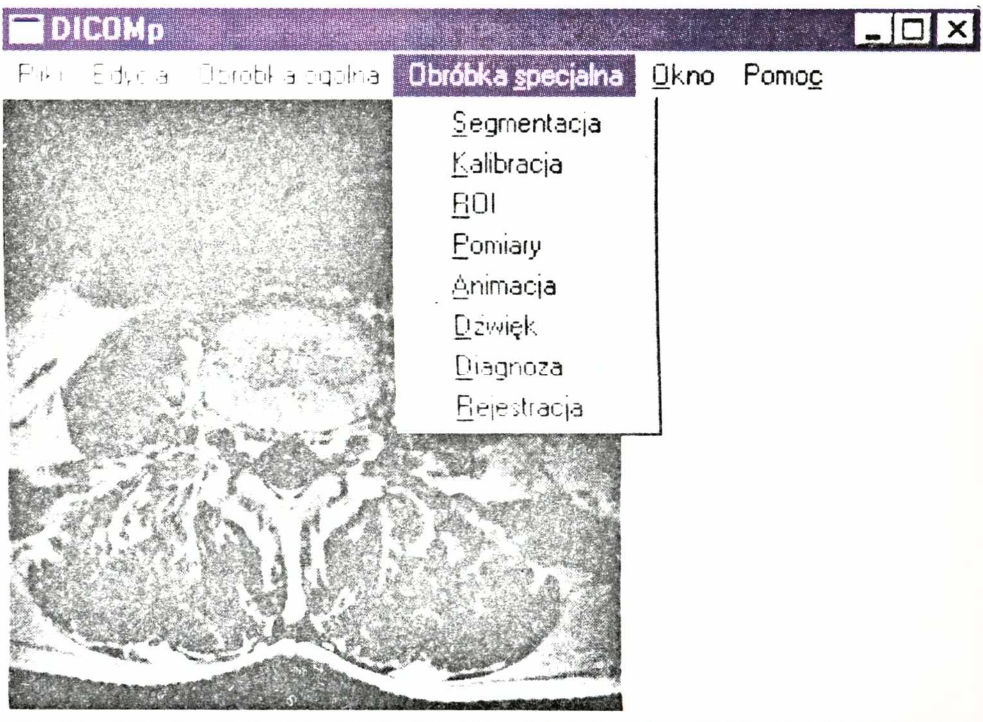

Figure 11. Example of our 2D, DICOM-based visualisation software — DICOMp [30].

One of the most powerful packages which we currently use for visualisation purposes in ElectroImpedance Mammography project (the above figure presents some examples from this project) is Advanced Visualisation Software — AVS (fig. 12). This powerful package runs on Sun Ultra 1 computer with support from supercomputers for calculations. Another package from this family — AVS/ Express was used for 3D volume generation from MRI cross-sectional images. This software allows to create dedicated application (developers version) so it is much easier to perform similar tasks. With products from AVS family, a user can generate application in LEGO-like method. This means that data processing and visualisation tasks are divided in blocks, so the user can create simple workflow from data creation/reading block to data presentation block.

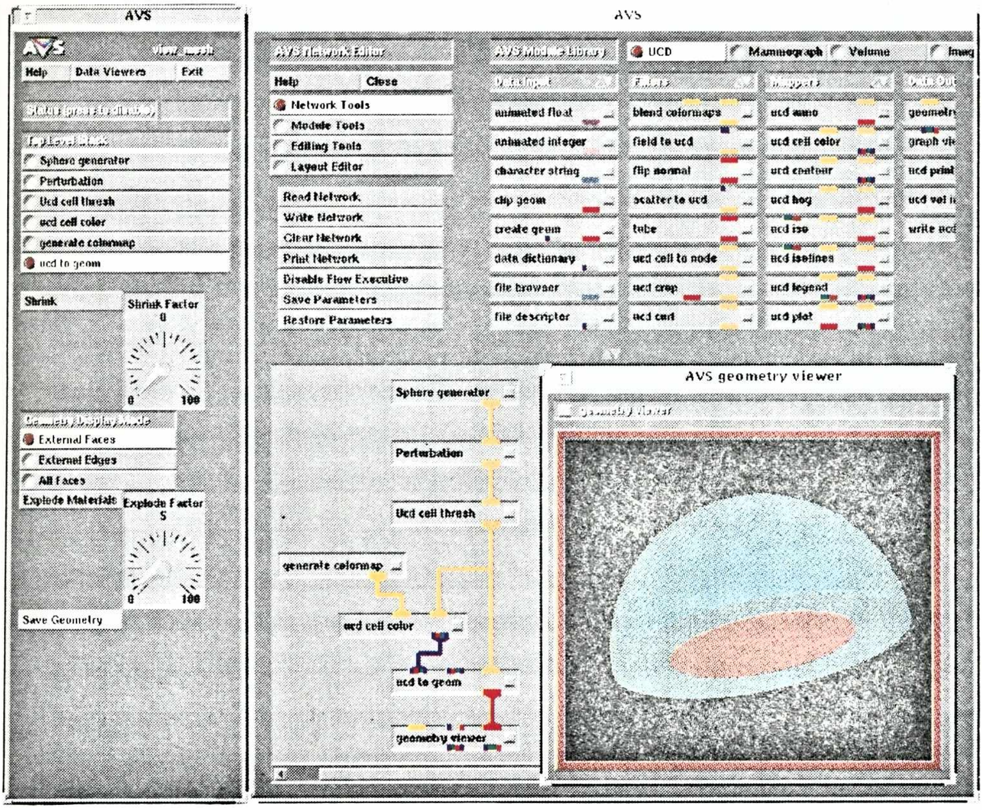

Figure 12. AVS — Graphical user interface.

Another commercial software we use for medical visualisation goals is MSC/ Aries. This package co-operates with MSC/EMAS for electromagnetic calculation and with MSC/Nastran for mechanical analysis. MSC/Aries allows to define materials, geometry, boundary conditions and excitation in graphical form and after calculation allows to observe results of analysis (fig. 13).

MSC/Aries and MSC/Emas are used for electromagnetic field modelling inside human body with presence of external excitation. We hope that such models could help us to solve many problems concerning non-invasive, as EIT, methods of medical diagnostics.

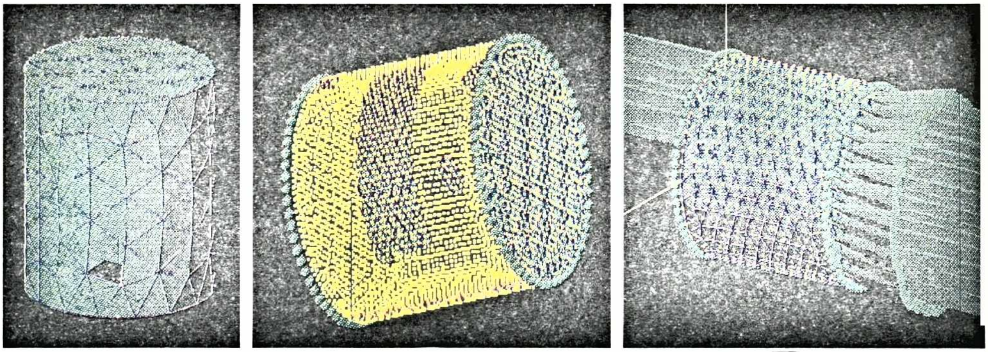

Figure 13. *Different examples of visualisation possibilities in MSC/Aries software (geometry and FEM mesh, Nodes and potential values, current flow through geometry).*

6. Conclusions

Visualisation plays a very important role in medical diagnostics and research. Proper information encoding into visual form allows to make decisions in a very short time, which is often crucial in the medical field. Visualisation techniques help to present data in the best way. In medical applications such techniques can improve presentation of original data which are usually obtained with finite resolution. Finite resolution of medical images (tab.1) [31], two-dimensional character of such images, presence of acquisition noise and other reasons presented above in this paper are basic needs of application of visualisation techniques in medicine.

Table 1. *Typical medical images resolutions and study sizes [31].*

Imaging modality	***No of pixels and bytes per pixel***	***MB per image***	***Mean study size (set of images), MB per patient***
Conventional radiographs	2048,2	8	16
CT (per slice)	512,2	0.5	22
Nuclear medicine	32-512,2	0.002-0.5	4
Ultrasound	512,1	0.25	7
MRI (per slice)	256,2	0.125	13
Mammography	4096,2	32	150
Fluoroscopy	1024,1-2048,2	1-8	57

Development of modern visualisation techniques as well as modern image and volume formation algorithms development leads to better understanding of human anatomy and physiology. Results presented by visualisation techniques improve research progress in different fields, especially in non-invasive medical diagnostic methods.

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