K.-H. Englmeier

Institute of Medical Informatics and Systems, GSF, Neuherberg, Oberschleissheim, Germany.

Commentary

Reflections on Robb's paper: *Dynamic Three-Dimensional X-Ray Computed Tomography of the Heart, Lungs, and Circulation*

In 1979 no clinical method was available for accurate visualization and quantitative measurement of the fundamental determinants of cardiovascular and respiratory function. This comprises the full temporal and spatial distribution of myocardial and pulmonary dynamics, and the spatial distribution and magnitude of blood flow in all regions of the heart and lungs, upon which myocardial and pulmonary dynamics depend. At that time, most progress was achieved by a decrease in scanning time and an improvement of image quality of commercially available X-ray computed tomography (CT) systems.

Commercially available whole-body scanners of that time produced remarkably accurate and diagnostically useful images of single cross-sections in many regions of the body. However, due to their limited axial range and resolution, and relatively long scanning time they could not provide a high spatial and temporal resolution of transaxial images over the entire anatomic extent of moving organs such as the heart, the lungs and the circulation. This is required for accurate, quantitative studies and assessment of the structure and function of these organ systems.

Therefore, the authors developed a system for high temporal resolution synchronous scanning of large cylindrical volumes of the body using X-ray video imaging techniques. This approach enabled recording of multiplanar images of the entire chest and its anatomical structures, with high spatial and temporal resolution. From these scans, dynamic, three-dimensional (3D) reconstructions of intra-thoracic organs could be accurately determined.

A critical look 20 years after that development raised two to questions:

1. What aspects of that development have influenced the field of medical informatics?
2. What early views expressed in that paper are still valid?

The first and most important aspect of the approach of Robb and colleagues [1] is the influence on medical imaging systems. Today's volume scanning with spiral CT is the ultimate accomplishment in computed tomography. This method acquires entire anatomical volumes without interruption, in the shortest time now possible, offers significant diagnostic advantages, compared with slice-by-slice scanning, such as:

- Shorter examination times (a full 360° scan in just 750 ms).
- Potential reduction of contrast usage.
- Elimination of slice misregistration.
- Improvements in MPR, 3D and CT angiography.

Another innovative offspring of CT technology is electron beam tomography (EBT), especially developed for imaging the beating heart at a sufficiently high speed. Instead of a mechanically rotating X-ray tube, an electromagnetically steered and precisely focused beam of electrons is scanned around a tungsten target. The resulting collimated fan of X-ray photons is rotated to provide scans in 1/10 or 1/20 second, an order of magnitude faster than conventional CT scanners.

These characteristic short scanning times of spiral CT and EBT are described as the most dramatic trend in the development of improved CT systems for clinical applications. In 1979, Robb et al. extrapolated the scanning times and predicted the availability of subsecond scanning EBT with a scanning time of 100 ms (Fig. 1).

This improved capability of CT, to

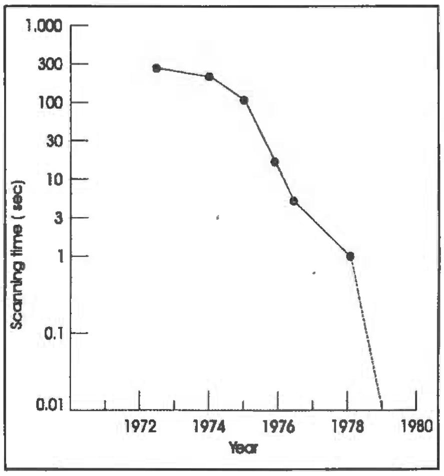


Fig. 1: Improvement in scanning speed of CT systems, as a function of time

acquire volumetric data sets with near isotropic voxels, has resulted in increased use of 3D rendering techniques for clinical applications. Such techniques allow the radiologist to view anatomical features and functional interrelationships explicitly, which offers additional advantages. However only few image analysis and synthesis systems are used in clinical practice. For example, many computer graphics methods have been developed, but time-consuming and CPU-intensive procedures such as ray tracing and volume visualization, as well as the suboptimal results of automatic 3D image processing and analysis methods, make widespread clinical use impossible.

In the last few years, a new generation of workstations enabled physicians to realize 3D rendering applications for diagnosis and surgical planning. These applications allow users to

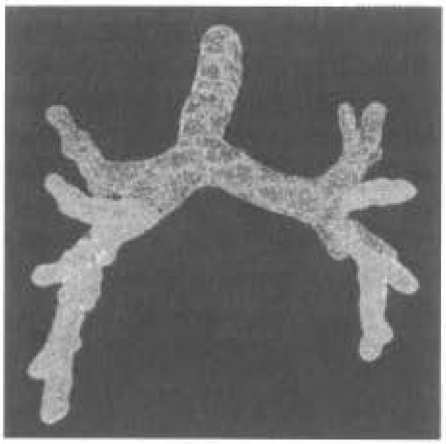
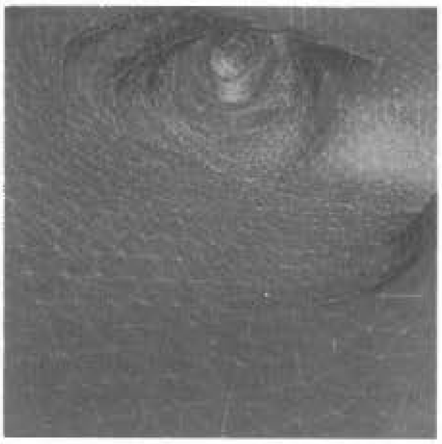


Fig. 2. Shaded wire frame presentation of the trachea.



classify the volume to view appropriate features, cut away and rotate the volume to the best view, or cut back and forth through the volume to better view interior features in less than 60 seconds. As the barriers to fast interactive visualization have disappeared,

Fig. 3. Surface-rendered abdominal scene.

interesting new applications for 3D rendering are becoming available:

- Simultaneous display of multidimensional and time-dependent or functional image information.
- Improvement of quality and accuracy of 3D rendering techniques.
- Increase of visualization speed to support real-time applications.
- Application of volume rendering to large image volumes in real time.
- Development of virtual-reality techniques in medicine.

Two rendering approaches exist in the realm of medical visualization, depending on the data representation:

- Surface-rendering techniques.
- Volume visualization methods.

Surface rendering visualizes the results of image segmentation and contour detection of interesting anatomical structures within the 3D image. The underlying data representation is described by wire frames (see Fig. 2 for example). This kind of representation allows exceptionally fast visualization.

Surface representations must be extracted from the tomographic image data after the segmentation of regions of interest. Subsequent visualization of the computed surfaces can be achieved by flat or constant shading techniques, Gouraud shading or Phong shading.

In contrast to surface visualization techniques, *volume* rendering methods do not necessarily need image preprocessing, such as segmentation and contour definition (Figs. 3 and 4). The original volume data, containing the information of any tomographic imaging device, is represented by a cuberille model, an octree voxel list or a generalized voxel model.

These data representations allow the application of various shading techniques to visualize the original gray value data volume or segmented binary data volumes.

With the further advancements in imaging, such as 3D display and communication of medical images, digital imaging is the key to solving many problems in diagnosis and therapy. Computer-assisted diagnosis and com-

Fig. 4. Volume-rendered abdominal scene.

puter-assisted surgery rely increasingly on digital imaging. Typical examples are craniofacial surgery, neurosurgery and thoraco and abdominal surgery. For these applications, new procedures are being developed with the help of virtual reality and other 3D enabling technologies, combined with modern communication systems. They provide an integrated, informative and timely presentation of the 3D therapeutic data set.

Robb and colleagues obviously stood at the beginning of a rapid evolution in the development of 3D imaging, processing systems and present-day enabling technologies in health care. The impact of computer-assisted systems is visible in many medical subspecialities. New imaging tools and additional enabling technologies, such as multimedia, virtual reality and data communication, are destined to profoundly change health care. These technologies will fundamentally affect the way physicians carry out their diagnostic and therapeutic activities.

Reference:

1. Robb RA, Rittman EL, Harris LD, Wood EH. Dynamic three dimensional X-ray computed tomography of the heart, lungs and circulation. IEEE Trans Nucl Sci 1979;26:1646-60.

Address of the author:
K.-H Englmeier,
Institute für Med Informatik und System,
GSF – Forschungzentrum fur Umwelt und Gesundheit,
Ingolstadter Landstrasse 1, Neuherberg,
85758 Oberschleissheim,
Germany.
E-mail: englmeier@gsf.de