Viewing Operations for 3-D-Tomographic Gray Level Data

K. H. HÖHNE, M. RIEMER, U. TIEDE

Institute of Mathematics and Computer Science in Medicine(IMDM),
University Hospital Eppendorf, Hamburg, F.R.G.

Summary

Radiological examinations are increasingly based on sequences of cross-sectional images. In current clinical applications, the three-dimensional (3D) relationships contained in these examinations must be inferred by the observer through analysis of multiple two-dimensional (2D) images. In this paper, methods for the direct display of 3D gray level data are investigated. In the chosen approach, the 3D presentation of bone and skin surface serves to orient the viewer, while planar reformation and/or transparent projections can be applied for the assessment of soft tissue structures in regions of interest. The resulting images represent the original image data in a way that is more suitable for observation of 3D relationships than the conventional cross-sectional viewing mode. This may facilitate the diagnostic process and enhance the interpretability of the images. Routine clinical application of this technique requires special computer hardware.

Introduction

An ever-increasing number of medical diagnostic images are obtained from X-ray Computed Tomography (CT), Magnetic Resonance Imaging (MRI), and Positron Emission Tomography (PET), which produce sequences of two-dimensional(2D) cross-sectional slices. The current predominant method of analyzing these images is by sequential observation of individual 2D slices and the viewer's subsequent 'mental reconstruction' of three-dimensional(3D) relationships. Computerized reformations of CT scans have produced 3D perspective display of bony anatomy that have proved clinically useful in craniofacial surgery and orthopedics

(1,2,3,4,5,6,7,8,9). A general application of this procedure in diagnostic radiology is limited by the fact that only predefined surfaces (mostly bone) can be visualized and that all other information is not used or lost in the reformation process. The classic approach requires a-priori knowledge of the gray scale properties of the lesion in order that a restricted region for 3D display be selected. In diagnostic radiology , however, the aim of the diagnostic process is precisely to find and define such regions. It is thus generally not possible to produce a 3D presentation of structures other than bone or skin surface prior to viewing the original gray scale images. General diagnostic application of 3D display techniques therefore requires presentation of the gray scale range for analysis. A few recent investigations have dealt with the software and hardware problems of displaying 3D tomographic volumes that preserve the entire original gray scale data (10,11,12,13,17). It is the objective of this paper to evaluate viewing operations that allow the exploration of gray level volumes.

Material

The viewing operations are demonstrated with five data sets as shown in table 1.

case	modality	matrix size	slices	device
1	CT	512 x 512	123	Siemens Somatom DR 3
2	MRI	256 x 256	128	Siemens Magnetom
3	MRI	256 x 256	128	Siemens Magnetom
4	MRI	256 x 256	26	Philips Gyroscan

Table 1: Data used for the 3D-presentation

The images were produced with the program system VOXEL-MAN-8 (8 stands for eight bit gray scale resolution), that we have developed in our institute during the past two years. It is the extension of VOXEL-MAN-1 which works on binary data only. VOXEL-MAN-8 is written in PASCAL and implemented on a VAX-11/780 computer. The resulting images are displayed on a VTE Picturecom or a Comtal-Vision-One display system.

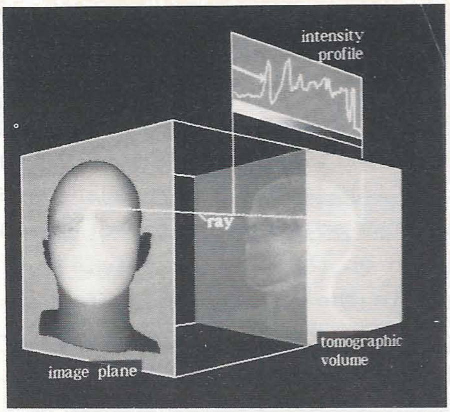

Fig.1. Principle of the ray tracing algorithm. In the shown example a simple distance image is produced from the intensity profile.

Method and Results

Preprocessing. To save storage space we compressed the CT values to a dynamic range of 256 gray values. To achieve cubic volume elements ('voxels') a linear interpolation of the intensity values between the original slices is performed. In order to produce a view from a desired perspective the entire image volume is rotated in the computer memory by resampling the data. Trilinear interpolation is used for the assignment of the gray scale values in the resampled volume.

Generalized projections. The rotated volume can now be viewed by a set of simple 'projections', as shown in fig. 1. The intensity profile along rays through the volume are analyzed and the computed parameters are written onto the image plane. One simple parameter is the distance of the skin surface (as shown in fig. 1), which produces a simple surface image when the distance is mapped into an inverse gray scale. There are various other parameters. The images obtained this way can be considered as generalized projections of the object onto the image plane. The following basic projections have been implemented and tested:

Projection of a surface. The computationally least expensive way of projecting a surface onto an image plane is distance shading, the computation of the inverse of the distance to each surface voxel. For a more realistic impression of the surface, shading methods (gradient shading) that take the surface inclination into account have been developed (2): In our implementation, gray scale data is utilized to produce surface shading based on the partial volume averaging effect. Here the gray values in the neighborhood of the surface voxel are used as a measure of the relative volume of adjacent tissue types(air/skin, soft tissue/bone) within the voxel. These relative volumes are related to the surface inclination. Thus the gray level gradient can be considered as a measure for surface inclination. This method ('gray level gradient shading') has been used in this study. It is described in greater detail elsewhere (14,15). Examples of a bone and a skin surface are shown in fig. 2.

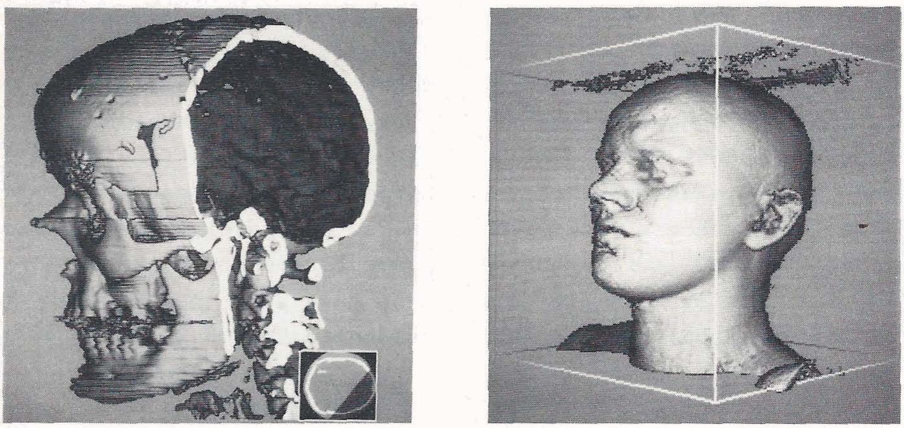

Fig.2. Surface images. Left: Bone surface of a skull with an oblique cut (CT, case 1). Right: Skin surface of a head (MRI, case 2).

Projection of cut planes. Here only the gray values in the chosen plane are used to produce a new tomographic image. This is in principle the same as conventional reformatting. When, however, the cuts are displayed together with the remaining skin surface, the orientation of the cut plane becomes apparent immediately. This is demonstrated fig. 4.

Transparent projections. In cases where the region of interest is not within a single plane, we can use an imaging mode similar to the classic X-ray projection. Here the intensity value in the image plane is computed simply by summing up the gray values in a certain range of the projection ray. In contrast to the classic X-ray technique, we can here choose which spatial range(depth) and/or intensity range is to be included in the projection. Fig. 3 shows as an example a look-through-projection of a layer of 2 cm along the skin surface of a human knee. As an advantage of this procedure vessels not being in one plane become visible in a single image. The same result is achieved when the same operation is applied to a human head.

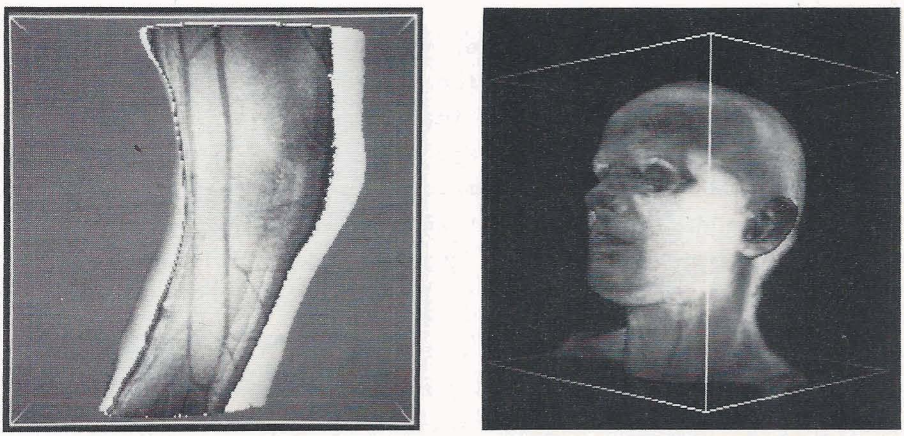

Fig.3. Selective transparent projection. Left: Layer of 1 cm along a knee (MRI, case 4). Right: Layer of 0.5 cm along the surface of a head (MRI, case 2).

The described procedure is unique in enabling us to produce new images by combining these projections in a variety of ways: Skin or bone surfaces are displayed primarily for the orientation of the viewer in 3D space. The diagnostic assessment, however, can be performed on gray level planes and/or transparent projections that can be variously combined into this coordinate system, according to the viewer's decision. Fig. 5 shows as an example of multiple surfaces a head where bone and skin have been peeled off thus opening up the view to the brain. The surface structure of the brain is different in both hemispheres. Views containing multiple cuts enable the "dissection" of the brain uncovering a tumor in the right hemisphere.

For the exploration of the correlation of different kinds of objects such as soft tissue and bone structures "selective reformatting" has turned out to be a useful tool (fig. 6). As an example reformatting is performed only for soft tissue with exception of a tumor. In a further example the bones around a temporomandibular joint (TMJ) are excluded from reformation and presented as surfaces. This procedure allows the assessment of the soft tissue structure around the TMJ.

Use of color. The described procedure differs from classic tomography in that a single image can contain more than one kind of pictorial representation. If this representation is displayed only in gray scale, image ambiguities may occur. For example the meaning of a certain shade of gray depends upon its location within the image. The assignment of a unique color to the different constituents of the image, such as cut planes or object surfaces, helps to ensure an unambiguous perception of the image.

Fig.4. Combined surface and cross-sectional images (MRI, case 2). The location of the MRI slice becomes immmediately apparent (left). Multiple cross-sections allow the 3D-exploration of the gray level volume (right).

Fig.5. Imaging a brain tumor (MRI, case 3). Left: A multiple surface image shows that the appearance of the brain is different in both hemisperes. Right: A dissection uncovers the tumor in the right hemisphere and allows the measurement of its location.

Fig.6. Selective reformatting allows the exploration of tissue structures around interesting 3D-objects. Left: Reformation around a tumor (MRI, case 3). Right: Reformation around a temporomandibular joint (CT, case 1).

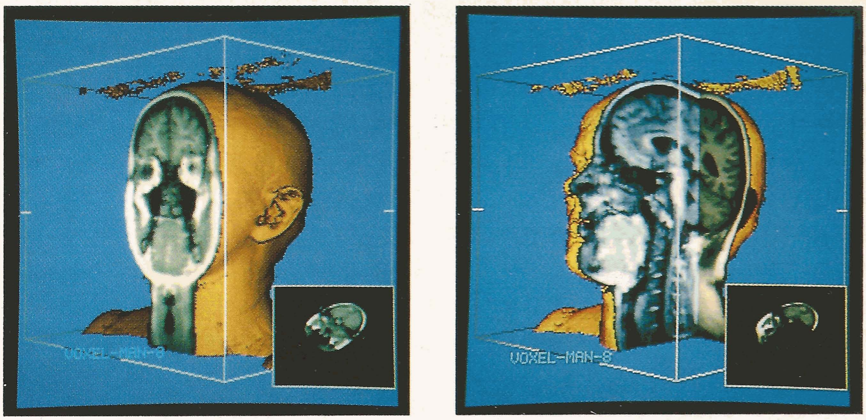

Fig. 4

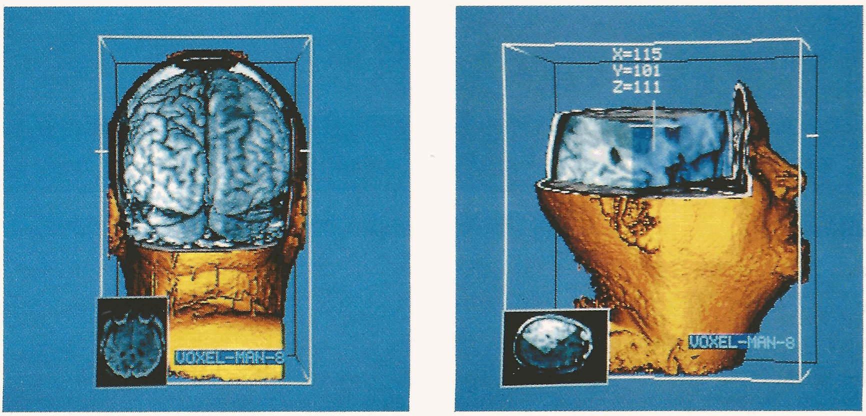

Fig. 5

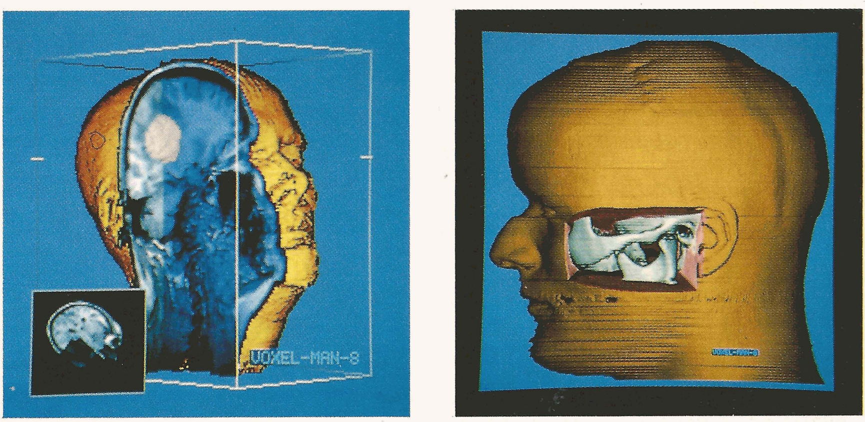

Fig. 6

Discussion

Relevance for radiology. Until recently, radiology was restricted to planar images of three dimensional objects. This restriction was due to technical limitations rather than to radiologic needs. In the past few years, we have become able to generate 3D images of bony structures, a technique that is increasingly used in craniofacial surgery and orthopedics. The methods presented in this paper extends the existing technology, applying it to diagnostic radiology so that we can view cross-sectional gray level image sequences in three dimensions. Once the three dimensional context of the outer surface and/or bone is available for orientation we can "navigate" visually within the object without having to rely upon a mental 3D-reconstruction.

Technical approach. For a clinical application the major technical problem involves the achievement of sufficiently high speed for an interactive operation. In pure surface display a variety of data structures can be used for the fast manipulation of 3D objects (1,3,7,16). If we want to rotate a gray scale object for inspection without knowing its structure (e. g. surfaces), we have basically the choice between two ways of implementation: 1) to compute the intensity values in the image plane from the original data whenever we make a projection, or 2) to rotate the CT volume once and simply scan lines or columns of the rotated matrices for the projections. The first technique is used effectively in most methods displaying surfaces only, since the original data are generally compressed to binary data describing a surface only. In some cases even further compression is applied (1). When we deal with gray level data we are confronted with at least 8 times more information (8 bits instead of one bit/voxel). In such cases the second approach has proved more effective in our study. It turned out that for inspecting the gray level information inside the object, a small number of viewing directions (three or less) are sufficient. The object can then be explored through simple variation of the projections. It is, however, decisive that perspective projection is used for the generation of the images. Otherwise cuts and windows do not look threedimensional.

In the experimental environment the rotation of a volume of 256^3 voxels took between 15 and 30 CPU-minutes. The projections took between 10 and 60 seconds each. Such times are certainly not sufficient for daily clinical work, but could be tolerated in a research environment. For routine clinical applications, more powerful hardware is definitely necessary. We are, however, convinced that hardware solutions should not be implemented until studies such as the present one have determined which operations are really useful. Otherwise it is possible that trivial properties, which the user might find useful, could not be included in the system.

Program	Object representation	"Projection"
VOXEL-MAN-1	1 bit: object/non object (binary voxel model)	surface of the object
VOXEL-MAN-8	8 bit: intensity parameters (gray scale voxel model)	surfaces, reformatted planes, look-through projections according to specification of spatial and/or gray scale window conditions
VOXEL-MAN-N	N-bit: intensity parameters + semantic attributes (generalized voxel model)	surfaces, reformatted planes, look-through projections of <u>objects</u> according to the specification of the conditions for the <u>objects</u>

Fig. 7. Evolution of the voxel model

<u>Future development</u>

The program VOXEL-MAN-8 can be considered as one step within an evolution from pure surface visualisation to an object oriented exploration of volume data(see fig. 7). In a further advanced state then projections such as 'show pathological regions of gray matter with transparent brain surface' could be possible. A prerequisite is an object representation, that also contains semantical attributes in each voxel (membership to a certain organ, normal abnormal etc.). The automatic determination of such attributes is nontrivial, but at least in the case of MRI not hopeless. As a first step towards the realisation of such a <u>generalized voxel model</u> within a system

VOXEL-MAN-N, we have implemented a second volume('attribute volume') that may contain attributes which presently are determined in an semiautomatic way.

Conclusion

We have demonstrated a method of viewing 3D tomographic data that uses 3D skin and bone surface display for the viewers orientation, while planar reformation and/or transparent projections can be applied for the assessment of soft tissue structures in regions of interest. Instead of being constrained to parallel planar images, we can 'navigate' within the threedimensional surface and bone anatomy and choose optimum viewing conditions according to the anatomic environment. The described software solution is certainly not yet fast enough for routine clinical application. For research application, however, the processing time (10 - 60 sec/view) with computers found in radiological research environments seems to be tolerable. For a final specification of clinical hardware solutions further research work of the described kind has to be done.

Acknowledgements

The authors would like to thank Drs. G. Witte and M. Heller (Dept. of Radiology) for many discussions, and Dipl.-Inform. M. Bomans for assistance in preparing the paper. We are also grateful to Siemens (Erlangen) for providing the MRI-volume data of the head.

References

1. Boecker, F.R.P.; Tiede, U.; Höhne, K.H.: Combined use of different algorithms for interactive surgical planning. In: Lemke U., ed.: Computer assisted radiology. Berlin New York Tokyo: Springer (1985) 572-577.

2. Chen, L.S.; Herman; G.T.; Reynolds, R.A.; Udupa, J.K.: Surface shading in the cuberille environment. Computer Graphics and Applications 5 (1985) 33-43.

3. Hemmy, D.C.; David, D.J.; Herman, G.T.: Threedimensional reconstruction of craniofacial deformity using computed tomography. Neurosurgery 13 (1983) 534-541.

4. Herman, G.T.; Vose, W.F.; Gefter, W.B. et al.:

Stereoscopic computed threedimensional surface displays. RadioGraphics 5 (1985) 825-852.

5. Lineweaver W.; DeLaPaz, R.L.; Federle, M.; Cann, C.; Barton, R.: Trengrove-Jones G.: Threedimensional Tomography of Facial Fractures. Submitted to Annals of plastic surgery.

6. Templeton A.W.; Johnson, J.A.; Anderson, W.H.: Computer graphics for digitally formatted images. Radiology 152 (1984) 527-528.

7. Vannier, M.W.; Marsh, J.L.; Warren, J.: Threedimensional CT reconstruction images for craniofacial surgical plannning. Radiology 150 (1984) 179-184.

8. Vannier, M.W.; Gado, M.H.; Marsh, J.L.: Threedimensional display of intracranial soft tissue structures. American Journal of Neuroradiology; 4 520-521.

9. Witte, G.; Hoeltje, W.; Tiede, U.; Riemer, M.: Die dreidimensionale Darstellung computertomographischer Untersuchungen kraniofacialer Anomalien. Fortschr. Roentgenstr. 144 (1986) 144,4 24-29.

10. Goldwasser, S.M.; Reynolds, R.A.; Bapty, T. et al.: Physicians workstation with real time performance. Computer Graphics and Appplications 5 (1985) 44-57.

11. Jackel, D.: The graphics PARCUM system: A 3d memory based computer architecture for processing and display of solid objects. Computer Graphics Forum 4 (1985) 21-32.

12. Lenz, R.; Danielsson, P.E.; Cronstroem, S.; Gudmundson, B.: Interactive display of 3D medical objects. In: Höhne KH,ed. Pictorial information systems in medicine. Berlin New York Tokyo: Springer (1986) 449-468.

13. Yasuda, T.; Toriwaki, J.; Yokoi, S.; Katada, K.: Threedimensional display system of CT images for surgical planning. Int. Symposium on Medical Images and Icons. Silver Spring MD: IEEE Computer Society (1984) 322-327.

14. Höhne, K.H.; Bernstein, R.: Shading 3D images from CT using gray level gradients. IEEE Transactions on Medical Imaging 5 (1986) 45-47.

15. Tiede, U.; Höhne, K.H.; Riemer, M.: Comparison of Surface Rendering Techniques for 3D Tomographic Objects. This volume.

16. Meagher, D.: Geometric modelling using octree encoding. Computer Graphics and Image Processing 19 (1982) 129-147.

17. Höhne, K.H.; DeLaPaz, R.L.; Bernstein, R.; Taylor, R.C.: Combined Surface Display and Reformatting for the 3D-Analysis of Tomographic Data. Investigative Radiology, (1987) in press.