Short Papers

Shading 3D-Images from CT Using Gray-Level Gradients

KARL HEINZ HÖHNE AND RALPH BERNSTEIN

***Abstract*—For the 3D-reconstruction of organ surfaces from tomograms, a shading method based on the partial volume effect is presented. In contrast to methods based on the depth and/or the angle of the voxel surface, here the gray-level gradient along the surface is used for shading. It is shown, that at least for bone and soft tissue surfaces, the results are superior to conventional shading. This is due to the high dynamic range of the gray levels within a small spatial neighborhood.**

I. Introduction

The 3D-reconstruction of surfaces from tomographic data such as CT is playing an increasing role in diagnostic imaging. Especially the 3D-display of bone structures is going to be a standard application in craniofacial surgery. In nearly all applications the voxel representation of the image data is used [1]–[3]. The simplest method of shading is depth shading, i.e., the projection of the 3D-image is produced by presenting the inverse of the distance from the image plane to the nearest surface voxel as a gray value. The inclusion of surface inclination for shading raises problems because of the coarse quantization of the surface angles due to the voxel structure. For the improvement of surface shading, we have tried out a simple algorithm, making use of the partial volume effect.

II. Method and Application

In a project dealing with the exploration of gray-level voxel scenes, we produce a voxel scene from a stack of tomograms by linear interpolation between the original planes. This scene can be rotated in three dimensions. Linear interpolation is used for the assignment of the gray levels in the rotated scene. Any projection of the 3D-volume onto an image plane is then easily implemented by scanning lines or columns of the data cube. Surfaces such as soft tissue or bone are defined as the first voxels exceeding a given threshold when scanning the data from the viewing direction (Fig. 1).

The gray value of a voxel represents the mean density within the volume element. If, for example, the density changes within the voxel from bone to tissue, the corresponding value is lower than that of bone. This effect is called the partial volume effect. It normally deteriorates the images, but we will show that this effect can be used to gain information about the surface structure. Under the assumption that the surface is due to a border between two regions of basically uniform material, the gray level is a measure of the ratio of the materials in the voxel. No information on the surface direction, of course, can be obtained from the gray level of a single voxel. This, however, can be done by considering the gray-level gradients in the neighborhood of the surface voxels, as shown in Fig. 1. The exact relation between surface angle and gray-level gradients is complicated and not shown in this note. Experimentally, an easily implemented shading is achieved, if the projected intensity in the image plane is computed as

$$I(i, j) = A \cos \left(\frac{g(i, j+1, k_T) - g(i, j-1, k_T)}{B} \right) \quad (1)$$

where $g(i, j, k_T(i, j))$ are the gray values at the depth $k_T(i, j)$ at which the surface threshold has been encountered. A, B are scale factors depending on the gray-level range of the original images (typically $A = 255$, $B \approx 100$ for 8 bit gray-level resolution. The cosine is taken in order to achieve diffuse reflection according to Lambert's law.

Fig. 2(b) shows the soft tissue surface of the head as recon-

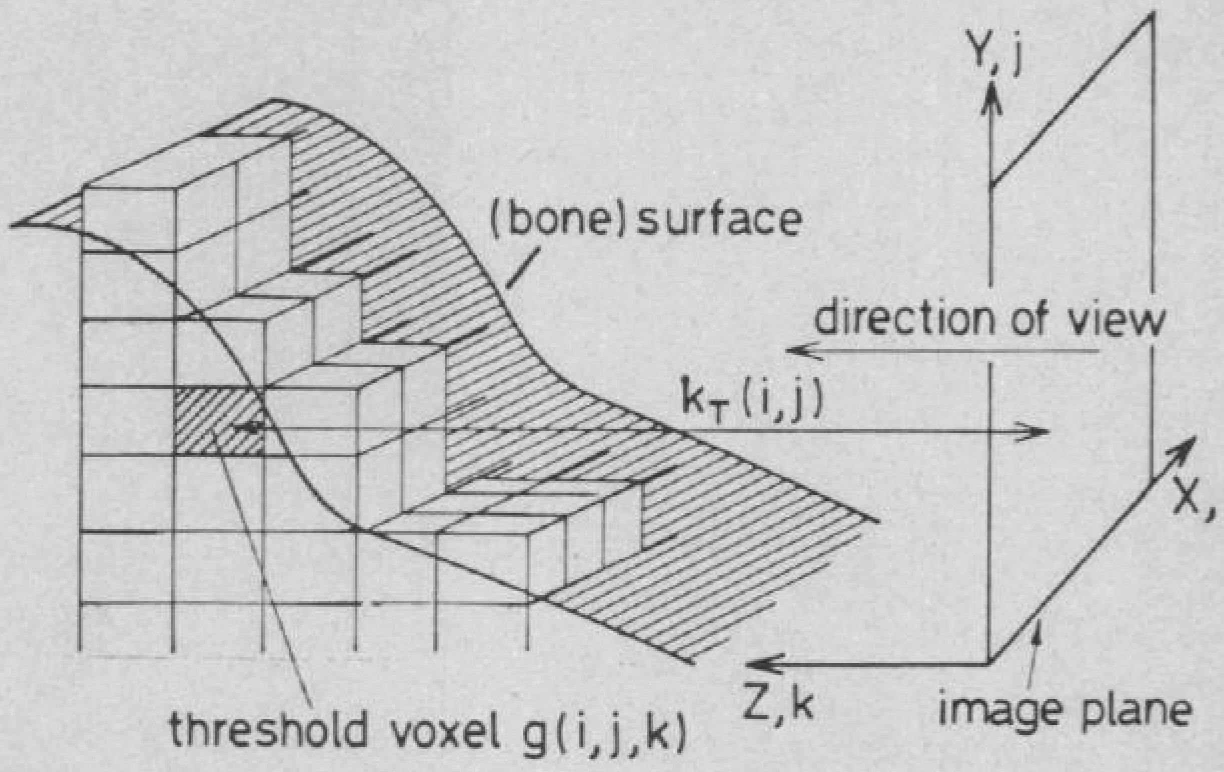
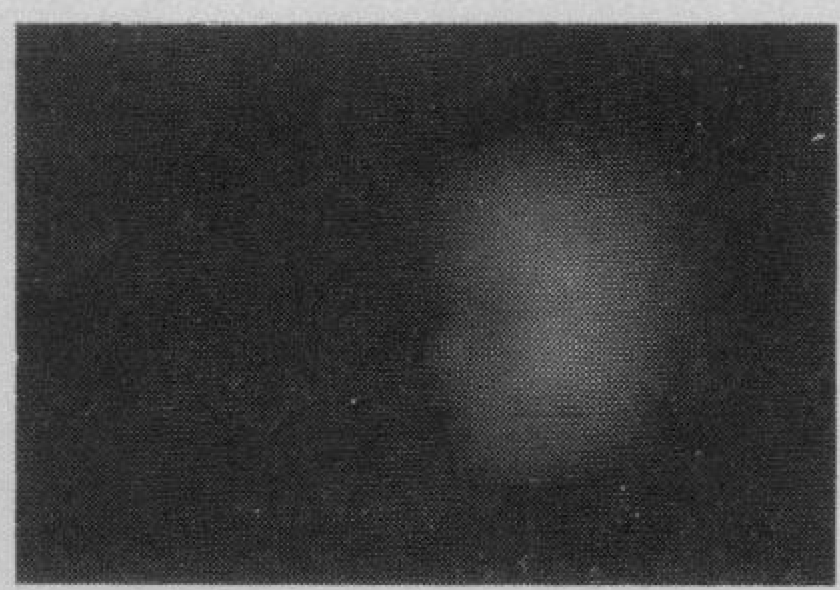


Fig. 1. Schematic drawing of the voxel neighborhood along a surface.



(a)

(b)

(c)

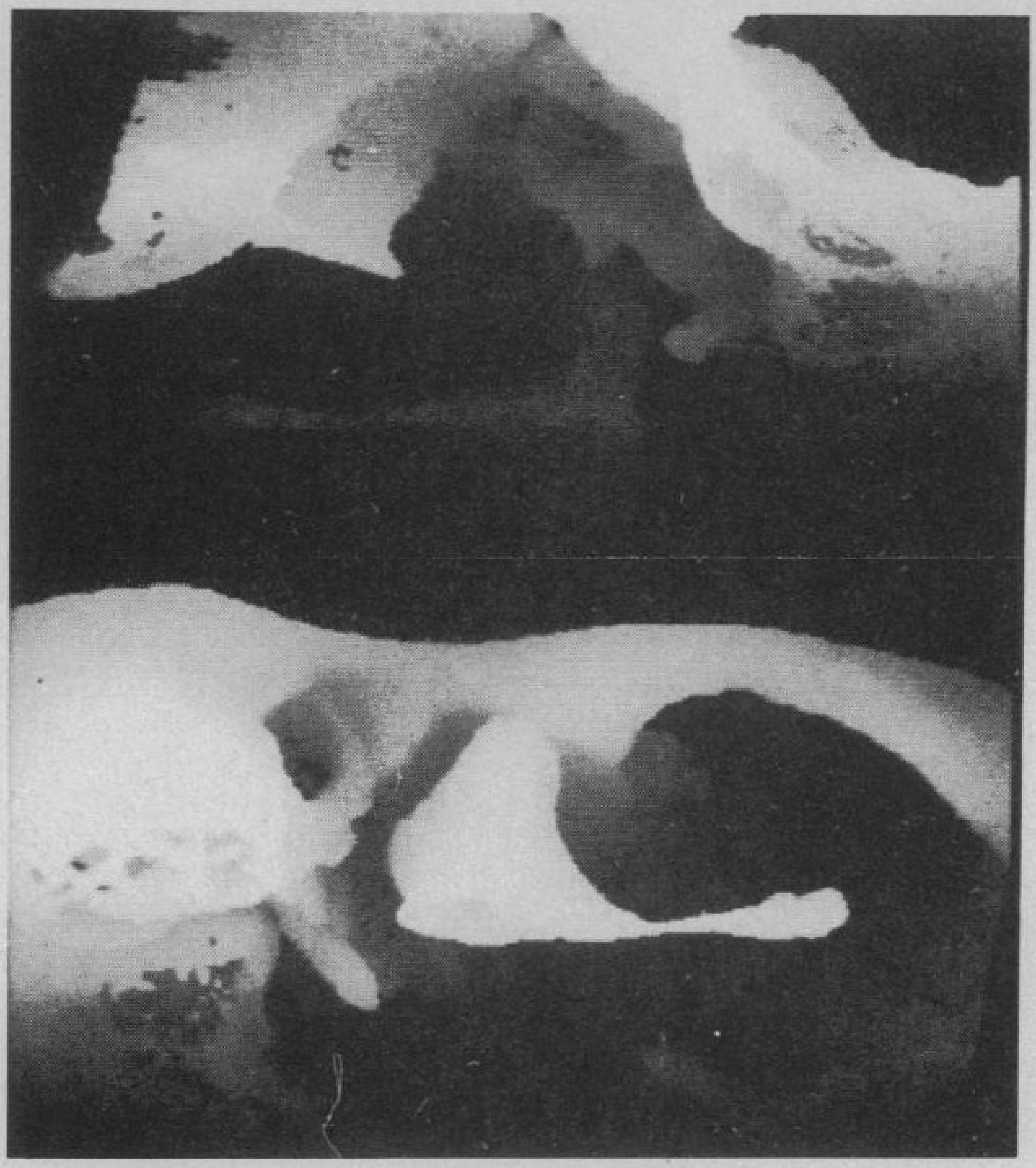
Fig. 2. 3D-display of a head: (a) with depth shading; (b) shaded according to (1); (c) shaded according to (2). The images show much more detail. At the same time deficiencies of image acquisition become visible.

Manuscript received November 11, 1985; revised December 8, 1985.

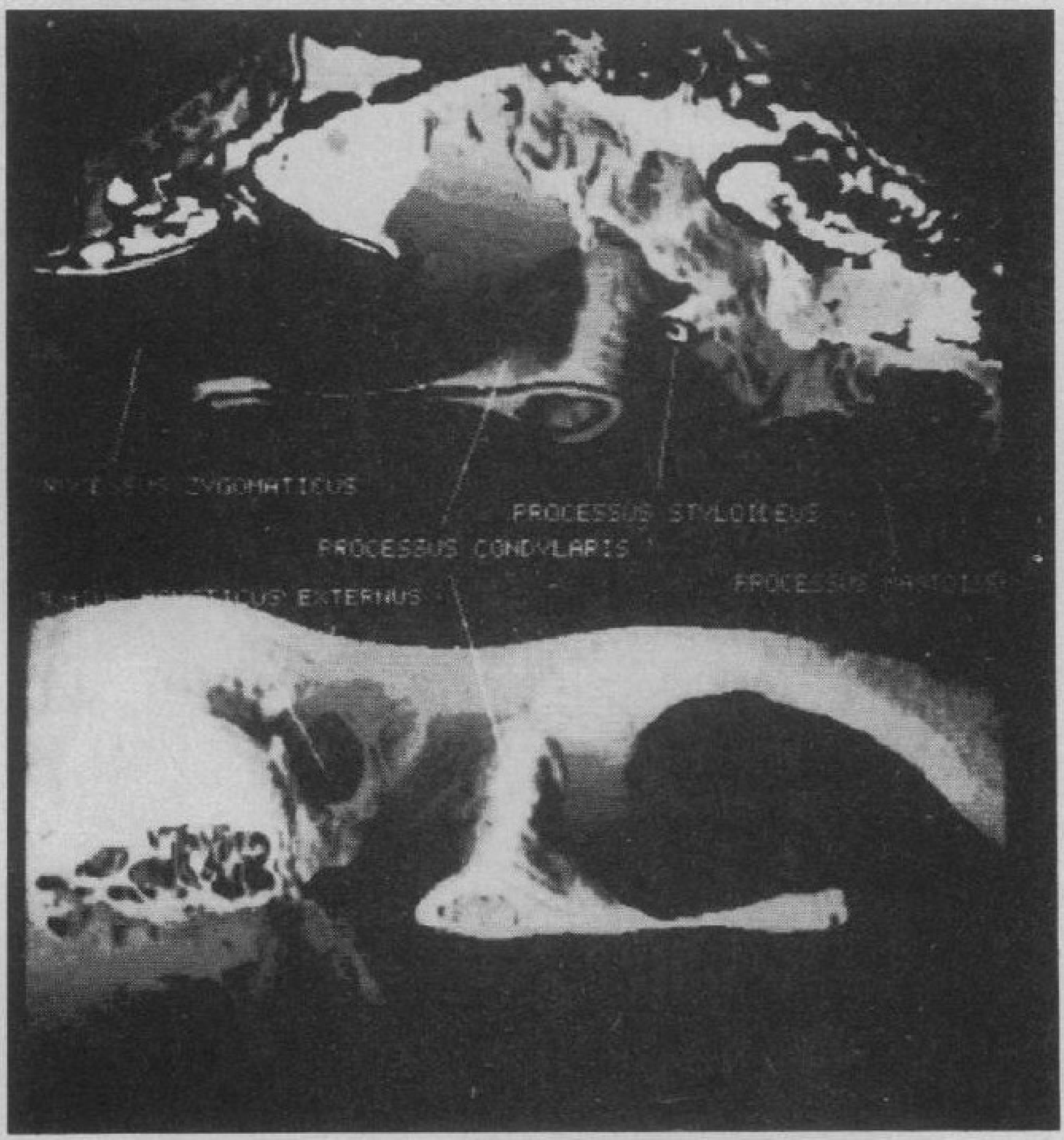
K. H. Höhne is with the Institute of Mathematics and Computer Science in Medicine, University of Hamburg, Hamburg, F. R. G.

R. Bernstein is with the IBM Palo Alto Scientific Center, Palo Alto, CA 94304.

IEEE Log Number 8607465.



(a)



(b)

Fig. 3. 45-degree medial (top) and lateral (bottom) view of a portion around the temporomandibular joint of a human: (a) depth-shading; (b) shaded according to (3). In addition the cut surfaces show the original CT values.

structed from a CT-sequence (80 CT-slices, 256 × 256 pixels) shaded according to (1). As compared to the depth-shaded image [Fig. 2(a)] more surface details are visible and the image as a whole looks more natural. In addition, the effect of different light incidence can be produced very easily by choosing gradients in different directions. The disturbance near the mouth is due to artifacts in the original data caused by metallic teeth fillings.

Rather unexpectedly, even the gradient in the viewing direction delivers meaningful images. Fig. 2(c) shows an image computed according to

$$I(i, j) = A\left(\frac{g(i, j, k_T + 1) - g(i, j, k_T - 1)}{B}\right). \tag{2}$$

Again the optical impression is better than that of the depth-shaded image. Yet there are moire-like artifacts resulting from the discrete nature of the surface voxel depth k. The black region above the ear is caused by a headholder with a density near that of soft tissue. Thus, the gradient is not representative for the tissue surface alone.

The aliasing effects can be reduced if the neighborhood considered is increased, e.g., by taking a 3 × 3 neighborhood above and below the surface voxel. It turns out that the addition of depth shading gives a further improvement. The resulting projected intensity would then be

$$I(i, j) = A \cos\left(\frac{\frac{1}{9}\sum_{l=-1}^{+1}\sum_{m=-1}^{+1}(g(i + l, j + s, k_T + m) - g(i + l, j - 1, k_T + m))}{B}\right) - C \cdot k_T. \quad (3)$$

where C describes the fraction of depth shading.

We have applied this shading to CT sequence of 20 slices of 512 × 512 pixels around the temporomandibular joint. Fig. 3(a) shows this scene as shaded with (3) compared to the same view in depth shading. It turns out that again the new method gives a more plastic representation of the object. Especially small surface details are more visible. In the case shown, the cut surfaces are represented by the real CT values.

III. Conclusion

In the case of surfaces, which represent borders between basically uniform material, the partial volume effect can be used for shading 3D CT-surfaces. In an experiment we show that the display of gray-level gradients results in images, that show more natural shading than, e.g., depth shading. This is basically due to the fact that the information contained in the gray-level data has a high dynamic range. For the same degree of smoothness a much larger neighborhood has to be considered, if the surface direction is derived from the gradient of the surface voxel positions, which results in a deterioration in the resolution of the surface. The effect of different light incidence can be produced by choosing gradients in different directions. The computing time for shading alone is comparable to that of depth shading.

Yet the method requires the access to the full gray-level data. Thus, at least eight times as much storage space is required as compared to binary scenes and even more as compared to special surface representation methods (1). It is, however, the opinion of the authors, that a broad use of 3D-methods in general radiology requires the availability of the gray-level data to the radiologist anyway. The method whose basic applicability has been shown in an experiment, should of course be refined by further investigations, which should allow the application of more sophisticated shading models (4).

Acknowledgment

One of the authors would like to thank the IBM Palo Alto Scientific Center for the opportunity to spend his sabbatical there. The authors would also like to express their gratitude to Prof. B. Taylor (UCSF, School of Dentistry) and Dr. C. Cann (UCSF, Department of Radiology) for their support.

References

[1] G. T. Herman, "Three-dimensional imaging from tomograms," in *Digital Image Processing in Medicine* (Lecture Notes in Medical Informatics vol. 15) K. H. Höhne, Ed. New York: Springer-Verlag, 1981, pp. 93–118.

[2] M. W. Vannier, J. C. Marsh, and J. D. Warren, "Three-dimensional computer graphics for craniofacial surgical planning and evaluation," *Comput. Graphics*, vol. 17, pp. 263–274, 1983.

[3] F. R. P. Böcker, U. Tiede, and K. H. Höhne, "Combined use of different algorithms for interactive surgical planning," *Computer Assisted Radiology*. H. U. Lemke, Ed. New York: Springer-Verlag, 1985, pp. 572–577.

[4] J. D. Foley and A. van Dam, *Fundamentals of Interactive Computer Graphics*. Reading, MA: Addison-Wesley, 1983, pp. 575 ff.