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THREE-DIMENSIONAL DISPLAY AND ANALYSIS OF SEISMIC VOLUME IMAGES

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Introduction

Seismic volume images made up of images of multiple parallel seismic sections are displayed in three dimensions utilizing the technique of projection imaging, a method originally developed to display medical volume images. Digital images of seismic sections are formed by digitizing the seismic traces, which make up the sections. For display purposes, a 127 x 127 x 127 seismic volume image of a physical model was generated. The volume image is made of the 127 sections each of which contains 127 traces. Each seismic trace was sampled at 127 time points (5 msec intervals). The magnitude of each sample (image picture element) is proportional to the trace deflection. For display purposes, only the positive deflection is utilized. The digital seismic section is transferred to the memory of a digital-to-video display system and then viewed as an image as shown in Figure 3. The display device converts the 2-D digital seismic section to a 2-D distribution of brightnesses where the brightness of each picture element (pixel) is proportional to the sample magnitude at that point.

Numerical Projection

Volume images made up of "stacks" of adjacent two-dimensional cross-sectional images are displayed in three dimensions using the technique of numerical projection (1,2) which is illustrated in Figure 1. The projection process extends the concept of a 2-D distribution of brightnesses into three dimensions to produce a "view" of a 3-D distribution of brightnesses. The three-dimensional array of volume picture elements (voxels) which make up the volume image is shown as the cross-hatched cube on the left. The two-dimensional array of pixels which make up the projection image is the center of Figure 1. The projection image is formed by summing the magnitudes of the voxels along the set of converging paths which project the volume onto a plane. The use of a coverging set of projection paths introduces the monocular depth cue of perspective into the resulting image. Four representative paths are shown illustrating the projection of four points on the left-most surface of the volume image onto the four corresponding points on the projection image plane. In practice, this process is accomplished by mathematically projecting each voxel of the volume image onto the image plane one at

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a time. The projection pixels function numerically as "accumulators," summing the contributions of all the voxels project. onto that pixel. The resulting 2-D discrete summation-projection image is scaled in magnitude and transferred to the memory of the digital image display device. When this image is viewed on a television monitor, it is as though the observer views the volume image with a single eye from the viewpoint, shown in the far right in Figure 1. What the observer sees i: the 3-D distribution of brightnesses. The process results in an image which has a "see-through" nature much like a conventional radiograph. Before projection, the volume image can be mathematically rotated to view the volume from any desire direction. The location of the center of rotation is arbitrary, although generally chosen near the center of the volume so that after rotation, the volume does not pass out of the effective viewing window defined by the projection image.

Selective Enhancement of Anatomy in Reconstructed Volumes

The process of combining a series of parallel cross-sectional images into a 3-D image can defeat one of the greatest advantages of the section image which is the elimination of superposition of structures (2). The problem of superposition in volume images is effectively overcome by utilization of the techniques of numerical "dissection" and selective "tissue dissolution" whereby obscuring structure is eliminated or partially "dissolved" from the three-dimensional data set before display (3). If these capabilities are integrated into the 3-D display system in an operator-interactive fashion, the user has the capacity to reversibly and non-destructively mimic several fundamental procedures commonly used in medicine by the pathologist such as the capability to "cut" or "peel" away obscuring structure to isolate a region of interest and then to "dissect" or "open up" the region for detailed analysis.

The effects of numerical dissection and selective tissue dissolution to enhance the visibility of selected portions of the volume image are illustrated in Figure 2. Shown are two projections of a 3-D x-ray tomographic reconstruction of a dog's chest seen from viewpoints which are 6° apart. X-ray reconstruction, referred to as computer assisted tomography (CAT), is a method whereby digital 2-D cross-sectional images of the body are obtained (4). Images obtained with CAT are anatomic cross section which are analogous to seismic sections. Multiple parallel CAT scan images form a volume image. In this example, the reconstructed volume is made up of 64 parallel cross-sectional images, each comprised of 64 x 64 picture elements, i.e., a 64 x 64 x 64 voxel volume image. The value of each voxel represents the x-ray "density" of a small cubic region of the chest with side dimensions of the cube of 3 mm. The volume has been mathematically rotated so that the dog is viewed from the left dorsal aspect (behind and to the left). The dog is oriented in a head-up position. Before projection, the volume image was dissected by removing all voxels in front of a plane between the heart and the spine and dissolving, i.e., "dimming," the voxels behind to that plane. Dimming is accomplished by replacing the value of each voxel with the product of the original voxel "density" value and a constant which is less than unity (a constant of 0.1 would result in a reduction of the magnitude of each voxel by 90%). The result is that the visibility of structure within the plane (actually a slice two voxels thick) is preferentially enhanced because the voxels representing "dense" superposed structures are either dimmed or totally removed.

Three-Dimensional Display of Volume Images

Both binocular and monocular depth cues can be utilized to assist viewers to perceive the volume image in three dimensions. The volume images are seen as three-dimensional by appropriately viewing two projection images (stereo-pair) generated at angles of "view" differing by a separation angle greater than 2° but less than 6°. The two panels in Figure 2 are stereo-pair projection images of the dog's chest. This image can be perceived in three dimensions by cross-fusing the images, i.e., viewing the image on the right with the left eye and the image on the left with the right eye. In three dimensions, the orientation of the highlighted coronal section and the spatial relationships of the structures in that slice to the anatomy behind the slice, such as the heart and ribs, are easily visualized.

The monocular depth cue of motion parallax, occurring as foreground objects passing in front of background objects, is produced by viewing a series of projection images generated as the volume is mathematically rotated in 2° angular increments around 360°. The rotation sequence is pre-computed storing the images on a video disc. When the sequence is played back rapidly, the volume appears three-dimensional as it rotates before the observer.

Display of Seismic Volume Images

A seismic volume image was obtained by scanning, in a water tank, a physical model consisting of five irregularly shaped raised acrylic stratigraphic lenses (scaled thickness 150 feet) mounted on a thick acrylic base. A total of 127 seismic sections were collected with 127 traces per line. Each trace was sampled at 127 equispaced time intervals (5 milliseconds) using a Biomation Transient Recorder (BTR), resulting in a 127 x 127 x 127 seismic volume image where the magnitude of each voxel was proportional to the amplitude of the trace. The effect of a triggering problem during digitization, while noticeable in the section images, cannot be seen in the volume image.

Figure 3 shows an image of a seismic section obtained by digitizing the positive deflection of the traces. In this image depth (time) is represented by the vertical axis with distance along the seismic line in the horizontal direction. The brightness of the image is proportional to the magnitude of the positive deflection, i.e., black regions are made up of samples with value less than or equal to zero. The bright reflection of two of the raised acrylic lenses appears in the upper center of the image. The top and bottom surfaces of the thick acrylic base plate appear as the two parallel horizontal lines in the center. The continuity of these later reflections is broken by the "shadows" cast by the raised acrylic structures.

Projections of the seismic volume were formed from two angles of view to form the stereo-pair shown in Figure 4. The orientation of the viewpoint is such that the observer is looking at the top of this model which is standing on its side. From this viewpoint, the five acrylic lenses appear as the five distinct white regions. Before projection, the volume was mathematically rotated about the vertical axis of the display system to view the model obliquely. In addition, the brightness of the voxels behind the raised acrylic plates has been selectively dimmed to enhance the visibility of the plane containing the raised lenses. The orientation of the brightened plane with respect to the volume image corresponds to the horizontal time slice section or Seiscrop™. The volume image is seen in three dimensions by cross fusion, i.e., looking at the left image with the right eye and right image with the left eye. In three dimensions, the location of the raised lenses relative to the baseplate is clearly visualized as well as the defraction patterns which propagate from those plates casting a shadow through the baseplate.

Conclusion

These preliminary results are encouraging. The direct visualization of the statigraphic lenses demonstrates the potential usefulness of multi-dimensional display of seismic volume images. Future plans include the display of new sets of unprocessed, wavelet processed, and migrated model tank data, as well as volumes of field data.

References

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NUMERICAL PROJECTION OF VOLUME IMAGE

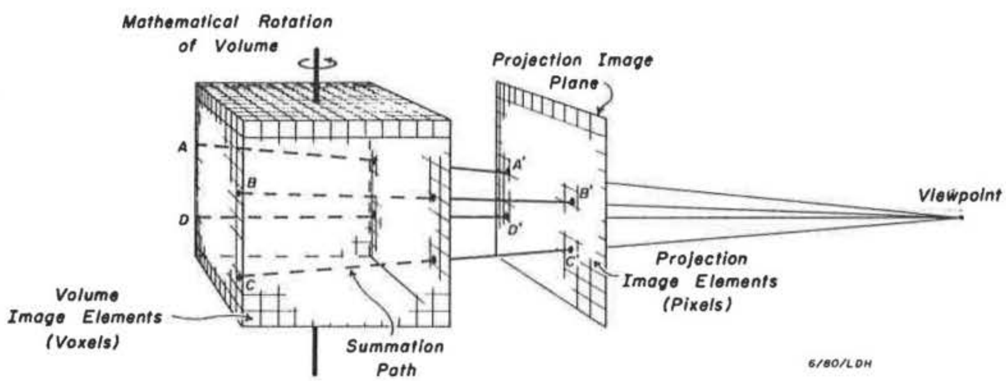

Figure 1 Diagram of the numerical projection process of display volume images. Picture elements (voxels) of the volume on the left are numerically summed along projection paths (four representative paths shown) to form the picture elements (pixels) of the two-dimensional projection image in the center. When the resulting digital image is displayed, it is as though the observer views the volume image from the viewpoint on the right. (Reproduced with Permission from Harris: Identification of the Optimal Orientation of Oblique Sections Through Multiple Parallel CT Images. Journal of Computer Assisted Tomography (In Press))

(Canine Thorax Viewed from Left Dorsal Aspect)

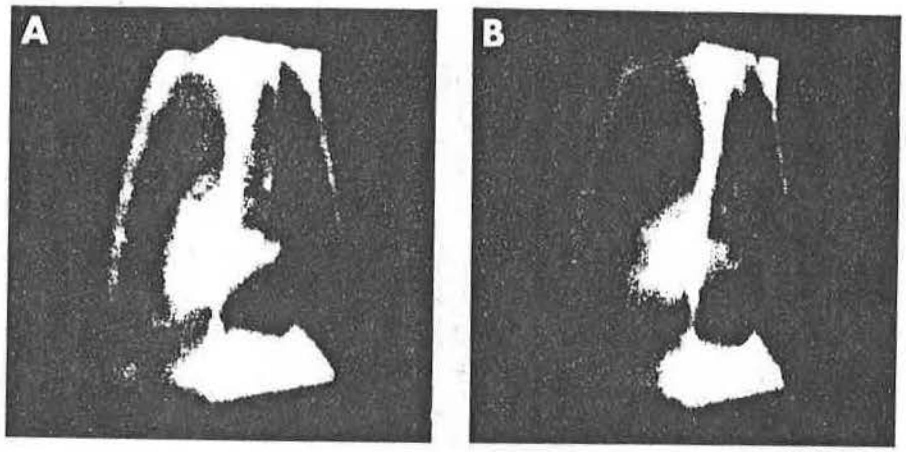

Figure 2 Stereo-pair projection images of the canine thorax. Before projection, the 3-D reconstruciton was dissected at a coronal plane just dorsal to the posterior surface of the heart. The thorax can be perceived as a 3-D scene by cross-fusing the images, i.e., viewing the image on the left with the right eye and the image on the right with the left eye. (Reproduced with Permission from Harris et al.: Visual Enhancement and Display of Three-Dimensional Reconstructed Anatomic Morphology. Analysis of Radiographic Images, New Port Beach, CA, June 20-21, 1979, pp 278-284)

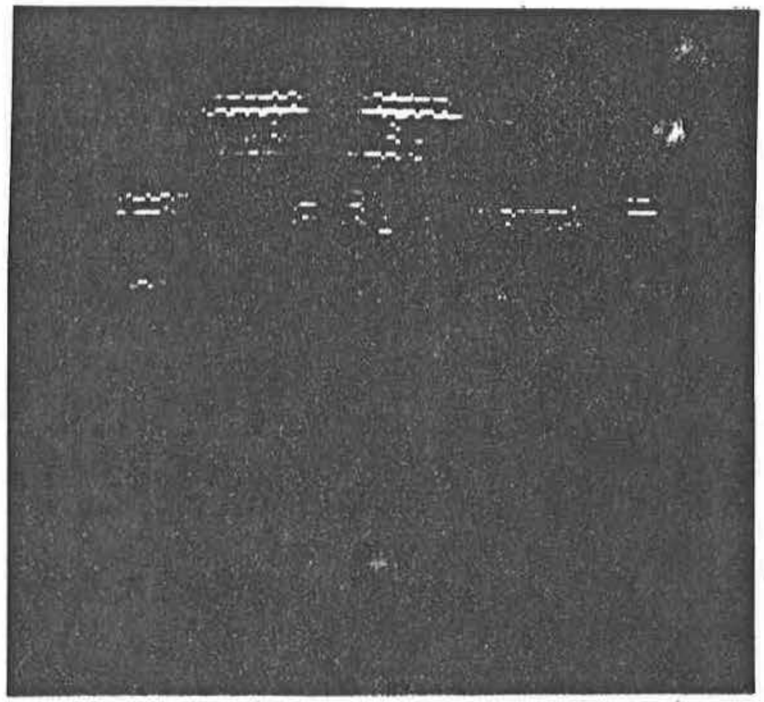

Figure 3 Digital seismic section image. Time (depth) is plotted in the vertical direction with distance along the seismic line in the horizontal direction. The reflection of two of the raised acrylic lenses is in the upper center region.

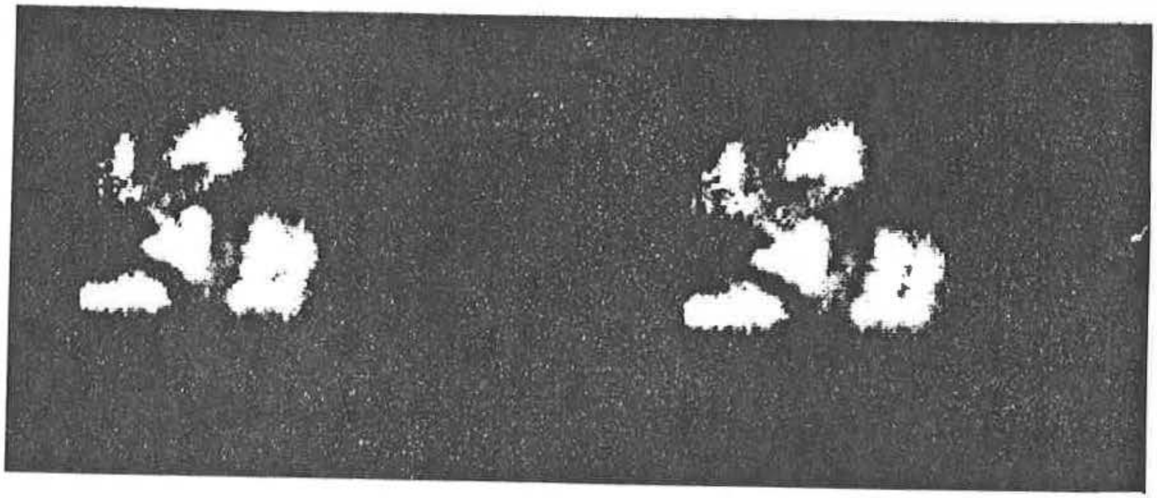

Figure 4 Stereo-pair projection images of a seismic volume image. The volume image is made up of multiple parallel seismic section images. The five white regions correspond to a horizontal section (Seiscrop™) through five raised acrylic stratigraphic lenses. The scene is perceived in three dimensions by cross-fusing, i.e., looking at the panel on the left with the right eye and the panel on the right with the left eye.