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論 文

뉴메리컬 프로젝션에 의한 3차원 탄성파 데이타의 영상화및 해석

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Stereoscopic Imaging and Interpretation of the three Dimensional Seismic Data by Numerical Projection

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要 約 천연가스나 기름의 매장 위치를 탐사할 목적으로 탄성파를 이용한 3차원 데이타를 수집, 처리, 해석해야하는 필요성이 요즈음 높아가고 있다. 본 논문은 이러한 목적으로 수집된 3차원 탄성파 데이타를 해석하고 영상화시키는 한가지 기법에 대한 연구 결과이며 3차원 탄성파 데이타 해석에 유용하게 사용되리라 생각된다. 3차원적 지하 구조물의 영상화는 2차원 영상을 스테레오쌍으로 만들어 겹쳐 봄으로써 구현 가능하다. 2차원 영상은 시각의 위치로부터 각점의 데이타 값을 프로젝션 함으로써 얻을 수 있으며 필요한 부분만 선택 처리 가능하다. 부분적인 선택 프로젝션은 외부에 나타나지 않은 구조라도 조사 분석할 수 있다. 이러한 방법을 이용한 2차원 영상의 실물화로 그들의 실재 위치를 밝힐수 있다. 탄성파 신호는 양의 수로 크기가 주어져 있으나 포락선 함수를 구하여 프로젝션 함으로써 보다 정확한 깊이감을 얻을 수 있음을 보였다.

ABSTRACT In recent years the acquisition, processing and interpretation of three dimensional seismic data, for the purpose of locating gas and reservoirs, have become practical. This paper explores one way in which the volume data can be searched and visualized, which may aid the interpreter. The illusion of looking at a three dimensional volume can be obrained by fusing a stereoscopic pair of pictures. Each picture can be made by projecting each data point of the volume into a plane from a point where the eye is placed. The data values along any projection line can be summed to form the picture, or only a segment along the line can be selected. By selective projection, the volume can be searched and obscuring layers removed. The stereoscopic pictures show the physical models in there true spatial positions. Projection of the envelope function of the seismic traces is shown to give improved depth perception compared with projection of the position amplitudes.

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1. Introduction

The concept of displaying a three dimensional data volume by numerical projection has been described by Harris et al (1980)[4,5,6]. The algorithm which is developed in this study projects each data value onto an image plane based on coordinates of the data points and the coordinates of the projecttion points.

The general purpose of the image reconstruction procedures is to process the data to form a pictorial image. In many scientific application it is often necessary to determine the distribution of some physical property (density, acoustic impedance, brightness, etc.) of an object under investigation[3]. The value of integrals of such a distribution can be deduced from appropriate physical measurements. The set of the line integrals corresponding to a particular angle of view is said to be the projection of the object.[1][3]. Given a number of such projections at different angles of view, the estimation of the corresponding distribution within the object is a basic problem of image reconstruction from projecttions.

A projection represents the N-1 dimensional representation of the N dimensional object. For example, an X-ray photograph is a two dimensional representation of a three dimensional unknown object[2][3]. This study will be concerned with the problem of processing seismic data to form images which facilitate interpretation. The measured three dimensional data are first reconstructed to form a three dimensional image. This three dimensional image is then projected into stereoscopic pairs of two dimensional images. In the porjection the three dimensional data can be weighted, or omitted, and thus objects can be seen which lie below obscuring layers by an appropriate choice of weighting.

A projection will be formed by weighting and adding all the structural details in a particular direction and thus with each projection we can associate an orientation. In general a single projection will provide a Aat flat view of the volume. But a pair of projections at different view points (we choose 5 degree deference in orientation) can be fused by the brain into a single three dimensional scene[3][5]

2. Projection theorem

A projection is an N-1 dimensional representation of an N dimensional object, just as an X-ray photograph is a two dimensional representation of a three dimensional unknown object[2]. A projection operator can be considered also as a mapping of N dimensional function to (N-1) dimensional function which is obtained by superimposing all information associated with a particular direction or orientation. A projection can be defined as the (N-1) dimensional function which results from such an operation. Thus

$$g_1(x_1) = \sum_{x_2} f(x_1, x_2) \tag{1}$$

$$g_2(x_2) = \sum_{x_2} f(x_1, x_2) \tag{2}$$

$$g_3(x_1, x_2) = \sum_{x_3} f(x_1, x_2, x_3) \tag{3}$$

are examples of projection functions. However, equation (1)-(3) do not represent the most general form for projections. The function $f(x_1, x_2, \cdots, x_N)$ is defined on an N dimensional vector space where the N variable $(x_1, x_2, \cdots x_N)$ simply represents a point in the domain of f.

The numbers $x_1, x_2, \cdots x_N$ simply represent coordinates. We can perform a change of variables and define another coordinate system. We can then define projections by integrating (summation) with respect to these new variables. Let A be a matrix which accomplishes a change of coordinates from the variables $x_1, x_2, \cdots, x_N$ to the variables $t_1, t_2, \cdots, t_N$, i.e.,

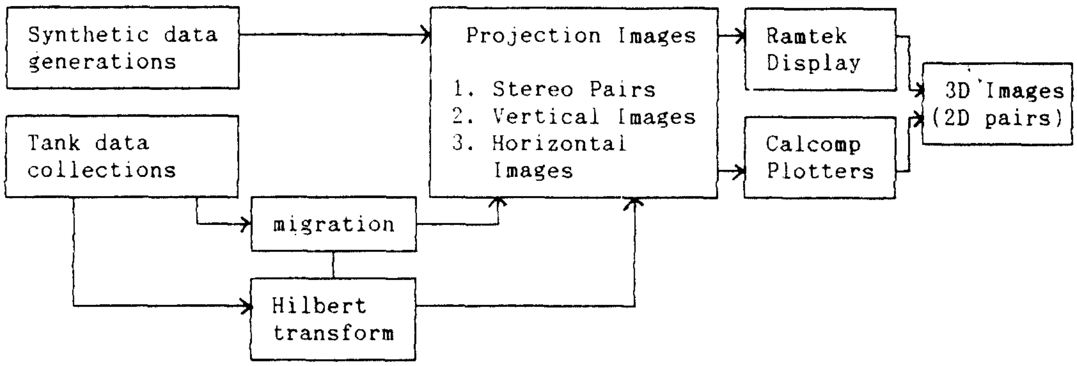


Fig. 1. Block diagram of image generation procedure.

$$\vec{t} = A\vec{x}$$

where $\vec{t} = (t_1, t_2, \cdots, t_N)$

$$\vec{x} = (x_1, x_2, \cdots, x_N) \qquad (4)$$

Since the change of coordinates is reversible, A must be invertable so that

$$\vec{x} = A^{-1}\vec{t}$$

$$\text{thus } f(\vec{x}) = f(A^{-1}\vec{t}) \qquad (5)$$

The left hand side of equation of (5) expresses the function in terms of the variables $x_1, x_2, \cdots, x_N$ and the right hand side of equation (5) expresses the same function in terms of the variables $t_1, t_2, \cdots, t_N$ where both sets of variables correspond to Cartesian coordinate systems. We can then define a projection as

$$g(t_1, t_2, \cdots, t_{i-1}, t_{i+1}, \cdots, t_N) = \sum_{t_i} f(A^{-1}\vec{t}) \qquad (6)$$

The projection which is define above is an N-1 dimensional function. The examples in equation (1)-(3) are all special cases of the above equation (6), where the matrix A is the identity matrix. What a projection is can be made clearer by considering the special case N=2. Let $f(x_1, x_2)$ represents the function which will be projected.

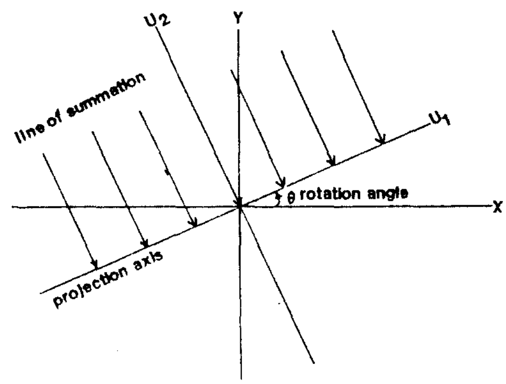


Fig. 2. Definition of projection in the time domain. Projection image which is generated by summing along the Y axis is on the X axis. If θ is the rotation angle (view point moves θ degree), projection image (along u_2 axis) is on the U_2 axis.

Then a new coordinate system can be defined, and the (u_1, u_2) coordinate system which is simply a rotation of the (x_1, x_2) coordinate system, as illustrated in figure 2. The matrix A is:

$$A = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix} \quad A^{-1} = \begin{bmatrix} \cos\theta & -\sin\theta \\ \sin\theta & \cos\theta \end{bmatrix}$$

$$\text{thus } x_1 = u_1\cos\theta - u_2\sin\theta$$

$$x_2 = u_1\sin\theta + u_2\cos\theta$$

$$\text{and } g_1(u_1) = \sum_{u_2} f(u_1\cos\theta - u_2\sin\theta,\ u_1\sin\theta + u_2\cos\theta)$$

$$g_1(u_2) = \sum_{u_1} f(u_1 \cos\theta - u_2 \sin\theta,\ u_1 \sin\theta + u_2 \cos\theta) \qquad (7)$$

The projection is obtained by summation along lines normal to the u_1 axis. Equation (7) represents the general form for a projection in two dimensions. The projection is completely specified by the angle θ which represents the orientation of the u_1 axis with respect to the x_1 axis. In general the different projections of a two dimensional function can be obtained by taking the projection according to equation (7) for each angle.

3. Projection algorithm

The process for generation of reprojection images of reconstructed volumes is illustrated in figure 3. The original volume elements of the reconstructed cross section at a single level are depicted as a two dimensional array of volumes contained within the perspective outline of the reconstructed volume. The outline of the reprojection image is on the left, with the image elements corresponding to the level of this cross section shown as a linear array of juxtaposed image elements. The amplitude of the signal values of the volume elements located along the projection paths perpendicular to the image plane, centered on each image element and passing through the reconstruction at each level, are summed to form the linear array of image elements in the reprojection image at the same level. Four representative parallel summation paths through the reconstructed volume are illustrated in this figure.

When all volume elements at a level K have been reprojected onto the appropriate image elements in the reprojection image, the volume elements at level k+1 are reprojected, and so on until all reconstructed volume elements have been reprojected onto the appropriate image elements. Before reprojection, the reconstructed volume can be mathematically rotated to view the reconstruction from any desired viewpoint. The center of rotation can be chosen arbitrarily, although generally chosen near the center of the reconstructed object so that after rotation the object does not pass out of the effective viewing window defined by the reprojection image. For all the reprojection images described here, rotation is performed one, or two, or three times around the each coordinate axis defined by the center of rotation and the direction of the levels, rows, and columns of the volume elements of the reconstructed volume.

The processes of mathematical rotation of the reconstructed object to obtain the view from which the three dimensional object is perceived may be conceptualized as a rotation of the object in front of the observer. Geometrical consideration for the reprojection of a cross section after mathematical rotation are illustrated in Figure 2. The reprojection image viewed from this orientation is the line below the cross section that has been rotated counter-clockwise by an angle θ about the center of the reconstructed array.

The reprojection process is one where by the value of each layer of volume is added to the appropriate reprojection image elements level by level. Computationally the volume elements function as accumulators which are cleared, i.e., set to zero, at the beginning of the process of the reprojection of each layer and get the value of next layer's. The appropriate image elements onto which each volume element V_{ij} is projected are identified by computing the point of intersection with the projection line at a given level perpendicular to the image plane which passes through the center of volume element. If the distance from the center of rotation to the center of each volume, v_{ij} in the i^{th} direction is given by x and in the j^{th} direction by y, then the distances X,Y between the points where the center of rotation and the center of V_{ij} project onto the line of the projection plane at level K are given by:

$$X = x \cdot \cos\theta - y \cdot \sin\theta$$
$$Y = x \cdot \sin\theta + y \cdot \cos\theta$$
$$Z = z$$

where θ is the rotation angle around the z-axis.

Here, X is the column distance, Y is the row distance, and Z is the level distance from the volume point to the image element point on the image plane. If we rotate again by the angle ϕ element around the coordinates axis X the distance X_2, Y_2, and Z_2 between the image element point and volume point are given by:

$$X_2 = X = x \cdot \cos\theta - y \cdot \sin\theta$$
$$Y_2 = Y \cdot \cos\phi - Z \cdot \sin\phi = (x \cdot \sin\theta + y \cdot \cos\theta) \cdot \cos\phi - z \cdot \sin\phi$$
$$Z_2 = Y \cdot \sin\phi + Z \cdot \cos\phi = (x \cdot \sin\theta + y \cdot \cos\theta) \cdot \sin\phi + z \cdot \cos\phi$$

X_2, Y_2 and Z_2 are the distance from the volume element location to the image element location in X axis, Y axis, and Z axis after the rotation around Z axis, and X axis by θ and ϕ degrees, respectively.

Figure 4 shows how the projected image value will be shared with nine neighboring image elements by weighting values. Weighting value can be decided by the distance from the

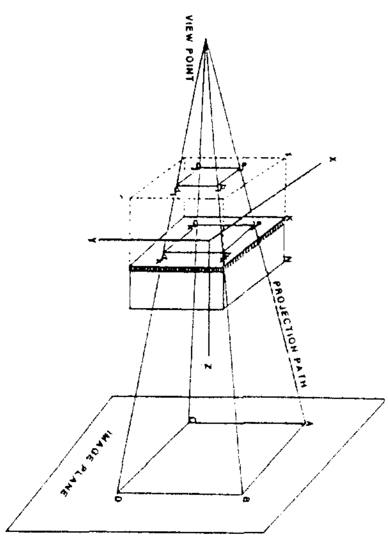


Fig. 3. a_1, b_1, c_1 and d_1 : volume elements on the first level.
a_K, b_K, c_K and d_K : volume elements on the Kth level.
X, Y, and Z : projection direction.
A, B, C, and D : projected image.

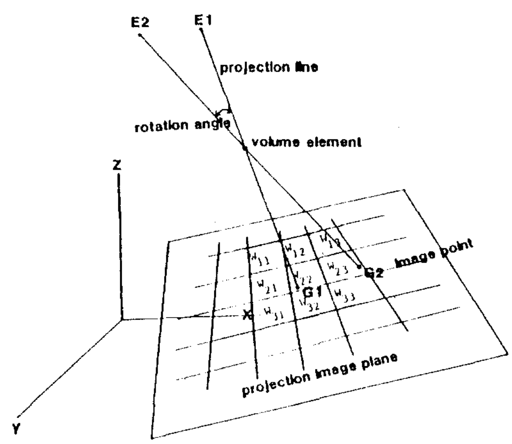


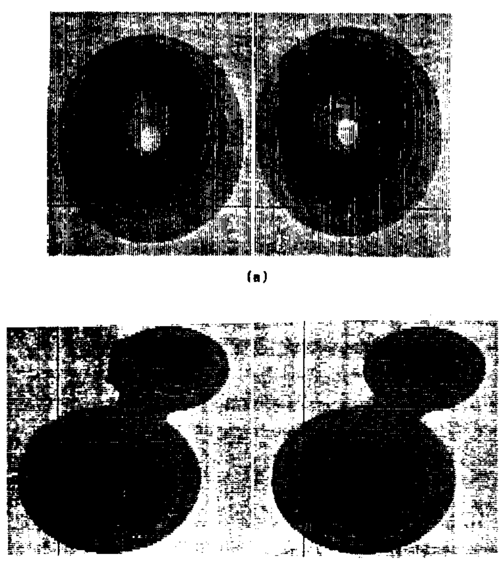
Fig. 4. Diagram of the projection process to display volume images. Picture elements of the volume are projected one by one and added to the output grid by interpolation. E1,E2 are view points and G1,G2 are the projected image points which are shared with nine neighbours.

image point to three neighboring image elements and given by:

$$W_{ij} = W_t(i) \cdot W_t(j) \; (i=1,2,3;\; j=1,2,3)$$

$$\text{where,} \quad W_t(1) = K_1 / K$$
$$W_t(2) = K_2 / K$$
$$W_t(3) = K_3 / K$$
$$K = K_1 + K_2 + K_3$$
$$K_1 = 1/D_1, \; K_2 = 1/D_2, \; K_3 = 1/D_3$$

D_1, D_2, and D_3 are the distance from the image point to each gridpoint which share the value of volume element in X direction and Y direction, or Y direction and Z direction, or Z direction and X direction in image plane.



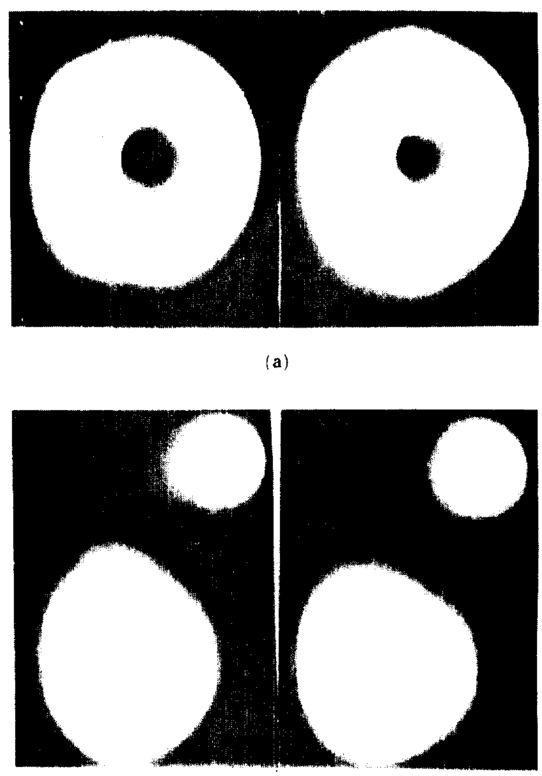
(a)

(b)

Fig. 5. Plotted stereoscopic pair of images of synthetic model after projection, this shows the clear contour of the model and stereoscopic pairs make clear 30 volume by fusing these images.
(a) A mountain with a deep hole in the center area.
(b) A mountain with two peaks.

4. Experiments and test

To generate the steropairs of projection images through above algorithm, we used VAX 780 system and displayed the image on the Ramtek 9050 graphic system. The flow diagram of the algorithm is shown in Figure 1. And to test this algorithm three data were chosen: two of them are computer generated sysnthetic data and the other is physical model tank data which are processed by three dimensional seismic migration. All of these data from a three dimensional volume, whose dimensions are 128 levels x 128 columns x 128 rows, although any size of data



(a)

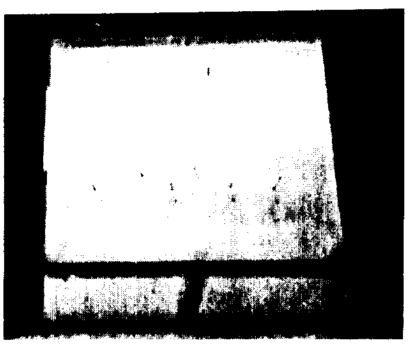
(b)

Fig. 6. Stereoscopic pair of images of synthetic model. These are images displayed on Ramtek.
(a) Synthetic model A
(b) Synthetic model B

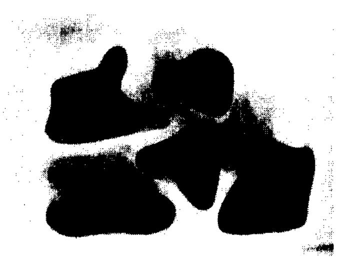
can be selected if computer memory size is sufficient. As synthetic model, two different shapes of volumes were generated. One is mountain with two peaks as seen in Figure 5. This mountain has two peaks which are different in height and their contours are ellipses with non-symmetric slope. The other synthetic model is also a mountain with a deep hole in the center area as shown in Figure 4.

Figure 5 is a contour plot with 4 gray level scale. The darker is the higher level. Physical tank data used in this paper were collected in physical modeling tank in the Seismic Acoustic Laboratory at the University of Houston and processed by two step migration method. As shown in the Figure 7, five thin plexiglas discs stand on a thick plexiglas with different levels. Figure 8 shows the dimensions of the model and data collection physical characteristics. The number on each thin plexiglas represents the level, 1 is the lowest and 5 is highest level. Real size of the model which is covered when all collected data is 9″ x 9″.

Originally the data collected this model



(a)



(b)

Fig. 7. Picture of the real physical model.
(a) A top view picture of the physical model. Five thin plexiglas discs are supported on thin columns above the thick plexiglas base plate.
(b) Picture of real model. The five plexiglas discs are coloured by black ink to get good pictures.

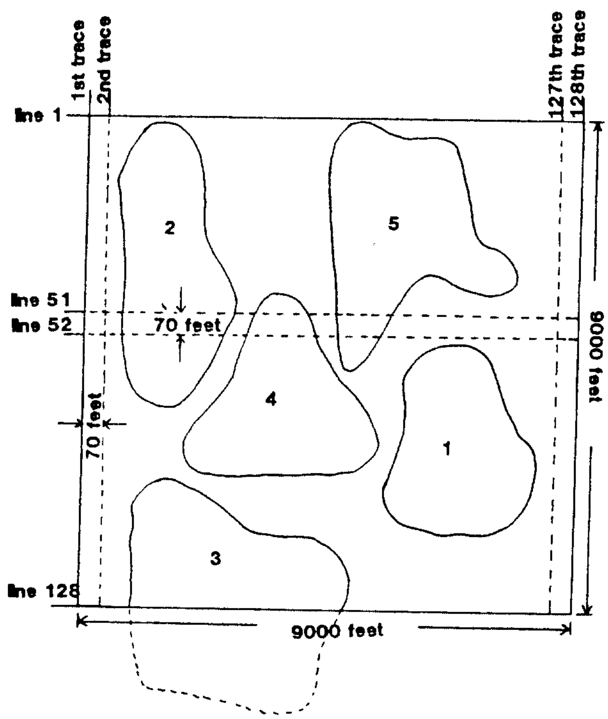


Fig. 8. Diagram of data collection map for physical tank data. Data collected area is 9″ x 9″ (128 lines X 128 traces). Five thin plexiglas discs have different levels. The number on the thin plexiglas disc represents the level (1 is the lowest and 5 is the highest).

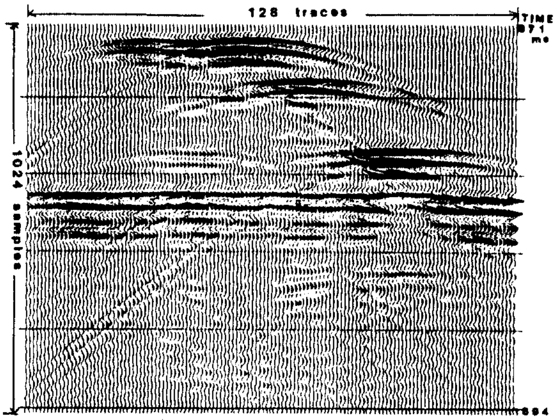


Fig. 9. Time section of physical model data. This is the time section of line 51. 128 traces and 1024 samples per each traces are plotted.

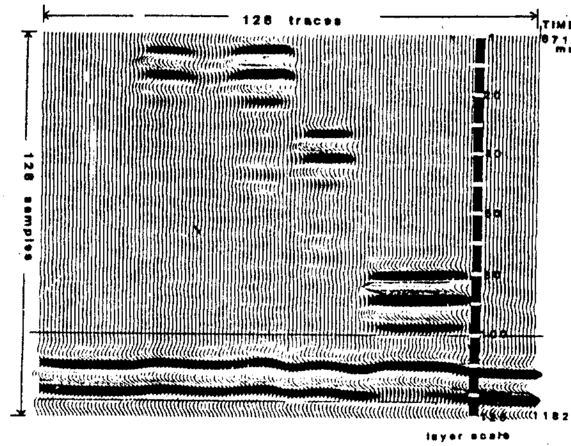


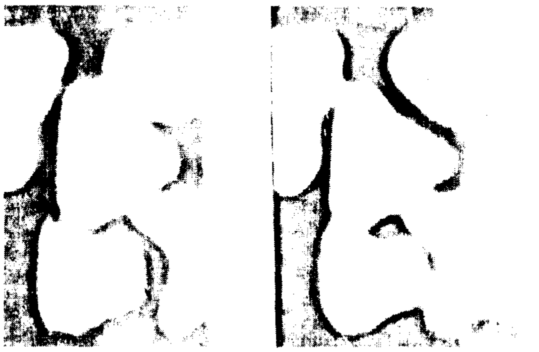
Fig. 10. Time section of migrated data which is selected only 128 samples per trace. Only five plexiglas discs and thick plexiglas portions are taken after resampled by 2ms.

consisted of 128 lines and 128 traces and 1024 samples per traces with sampling rate 1 ms. To make the data more convenient to process, these data resampled and abandoned in the beginning and in the end of each traces. Final data volume for projection is 128 lines x 128 traces x 128 samples as shown in Figure 10. When the volume element is projected by this algorithm, the positive amplitude values may be taken as the input values and negative values put to zero. But also the Hilbert transform of the migrated data may be taken, so as not to ignore the negative values, and the envelope projected. Above several kinds of data were processed to get the stereoscopic pairs of projection image with different rotation angles.

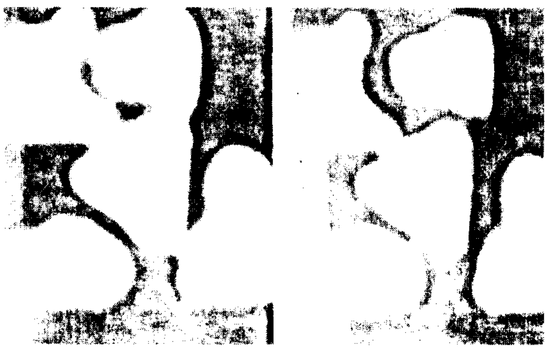
The visualization of reconstructed volumes in three dimensions can be accomplished by appropriately viewing two projection images which are generated at different view points by a separation angle greater than 3 degrees but less than 8 degrees[1][3]. Two such images taken together are referred as a "stereoscopic pair" or just "stereo pair". Stereoscopic pair images of three dimensional seismic volumes are shown in Figure 11. As seen in the previous section, to generate projection images several kinds of data were used. Figure 6 is the projection images of synthetic models of Figure 5. Figure 10 shows the reconstructed images of migrated tank data. When we project three dimensional volume only positive values are taken and negative values put zero. To save negative values these data were Hilbert transformed. After the Hilbert transform of each data, projection images were generated using the envelope magnitude before and after Hilbert transform. There is not a big differences between the two cases. But images in Figure 11(a) are brighter than images in Figure 11(b).

Even though we ignore the negative values of the data, there is not a big difference. That means only positive part is enough to represent the characteristics of the information of this particular data set.

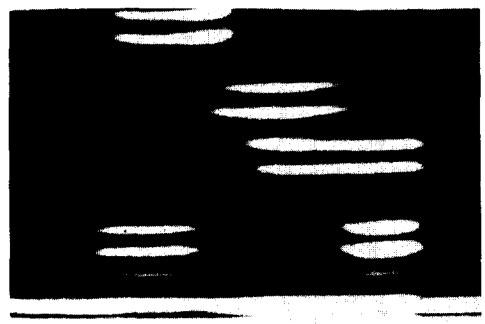
By three dimensional migration almost all of the noise is removed and we can see very clear images after projection and can identify the level difference by fusing the stereoscopic pair images. Figure 12 shows the vertical projection images



(a)



(b)



(a)

(b)

Fig. 11. 3D migrated data projected into stereoscopic pairs
(a) Projection images of the envelope function of the selamic amplitades.
(b) Projection images of the positive values only of seismic traces.

Fig. 12. Vertical projection images of migrated physical tank data.
(a) Projection image along the line direction.
(b) Projection image perpendicular to line direction.

of the model. Figure 13 is a series of projection images of the volume, each made from five consecutive layers. These shows that any portion of the data can be projected and this method will be very useful to interpret seismic data. Figure 14 shows the stereoscopic images of five layers near the thick plexiglas base. Figure 14(a) shows the images of just the reflection from the thick plexiglas and Figure 14(b) shows the data just above the thick plexiglas. Three two pairs are very different. In Figure 14(a), the black portion is the signal that passes from the thick plexiglas. Note that the vertical levels are the same as for the real model when we fuse the images. But in Figure 14(b) the black portion is the water and white portion is the tail end of the direct reflection from the thin plexiglas discs. When we fuse the images in Figure 14(b), the vertical levels of each thin plexiglas are the same as that of the real model. Stereoscopic pairs of projection images of particular portions of a data volume such as the series above, may be helpful for interpretation and velocity analysis of seismic data.

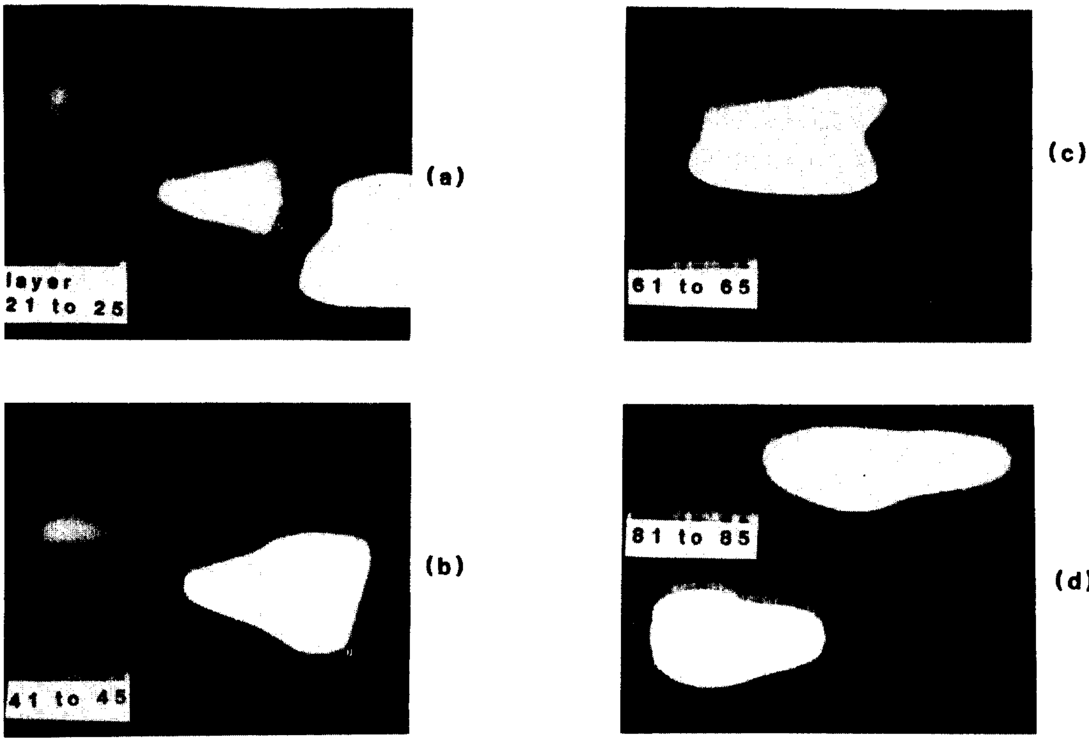
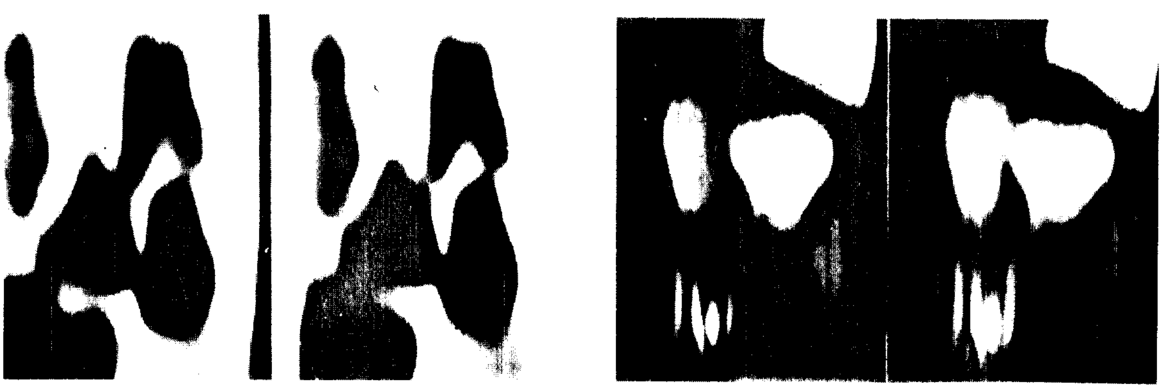


Fig. 13. Series of projection images of particular portion of the date.
(a) The highest thin plexiglas disc.
(b) The 2nd highest thin plexiglas disc.
(c) The 3rd highest thin plexiglas disc.
(d) The lowest thin plexiglas discs.
Each image is made by projecting five consecutive layers.



(a) (b)

Fig. 14. Projection images (stereoscopic pairs) of particular portion of migrated data.
(a) Just thick plexiglas base portion.
(b) Just above the thick plexglas base.

5. Conclusion

The technique of numerical projection has been developed for the display of three dimensional seismic volumes. Multiple projection images from any desired angle of view can be generated and viewed as a stereoscopic pair to achieve three dimensional display. If a series of projection images of three dimensional seismic volume were generated at 2 degree angular increments around 360 degree, the whole three dimensional volume will be perceived.

If this technique is joined with the technique of three dimensional seismic migration, it should be very helpful for seismic interpretation, as seen in Figures 11 through 14.

This study could be the first step for many future works. For example, (1) to construct the seismic volume projections in the frequency domain, (2) to display seismic velocity analysis, (3) to construct an interactive projection program using color graphics, (4) to study the use of orthogonal projections to reduce computation time, (5) to apply the method to field data, (6) to use other seismic attributes, such as phase angle, for projection.

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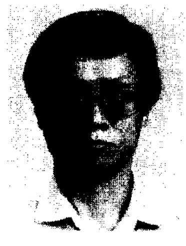

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