

# Feature Based Rendering for 2D/3D Partial Volume Segmentation Datasets

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## ABSTRACT

In this paper, a new feature based rendering algorithm for partial volume is presented. This algorithm utilizes both surface and volume information for the rendering of the partial volume segmentation data with associated features. First principal directions are extracted from the partial volume segmentation dataset to construct a feature vector dataset. Using the improved LIC (line integral convolution) algorithm, our rendering algorithm can integrate the feature dataset into the traditional volume rendering process. Combining the features and the traditional volume rendering, the partial volume could be visualized clearly. This can result in an improved diagnosis in clinic, because the partial volume quantities carry very rich diagnostic information.

**Keywords:** Line Integral Convolution, Partial Volume Segmentation, Volume Rendering, and Visualization.

## 1. Introduction

In the traditional segmentation algorithm, each fundamental element (pixel or voxel) of the medical scan dataset is classified into only one tissue type. Recent developed segmentation algorithms[5][6] do not assign each element to only one class, instead they utilize percentages to quantify the composition of each element. Thus, each element can contain several tissues, this is a partial volume dataset. Comparing to the traditional segmentation dataset, the partial volume dataset contains more information, which is clinical significant.

For a given segmentation dataset, there exist two foundational rendering methods: surface based rendering and volume based rendering. By the surface based rendering, the border surfaces of the interesting section are extracted first[1][2]. By displaying these surfaces with global illumination, it can reflect the surface information of the interesting section. Since this method displays only the surface information of the dataset, it does not show the inner detailed anatomical structure or tissue function of the dataset. Furthermore, this surface based method is suitable to the traditional segmentation data and is not adequate for the partial volume segmentation, since the partial volume data does not provide a definite border surface. If a border surface is constructed from the partial volume dataset, this surface will overlook many useful information. On the other hand, although the volume based rendering[3][4] can display the inner information of the dataset and it is more suitable for the rendering of volumetric data, it has been customarily developed for the traditional segmentation dataset. Applying the conventional volume rendering to partial volume segmentation dataset by simply averaging over the percentage quantities, the rich information embedded in the partial volume segmentation will not be fully realized.

There are few papers refer to the rendering method of this type of data. A volume based algorithm is introduced by Debrin[4]. Knowing that each voxel may be composed of several materials, this method combine the color and opacity by the percentage. That will result some blurring result at the border, it is hard to observe the shape information from the rendering image. Victoria Interrante[7] used a novel method to show the principal direction information on the surface. With the stroke information, the shape can be understood clearly. But she do not think about the partial volume, her method is suitable for the 3D surface more.

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In this paper, we propose a new rendering concept to fully realize the partial volume segmentation provided by advanced image classification algorithms. One of the features in the partial volume segmentation dataset is the principal direction on the iso-intensity contour/surface. This principal direction represents the link between the adjacent elements with the same percentage. A simple but efficient method is used to extract the principal direction of each element. The calculation of the principal direction is limited in a small adjacent domain, so the calculation expense is low. Using an improved line integral convolution (LIC) algorithm, the corresponding feature-based sparse stroke volume can be created. In this volume, all principal directions are converted to several sparse strokes. Combining the feature-based sparse stroke volume within the traditional volume based rendering procedure, the feature-based strokes can be integrated into the traditional rendering. Besides the inner information of the partial volume dataset provided by volumetric rendering, we can also visualize the features which could be overlooked in the traditional volumetric rendering.

The content of this paper is organized as follows. In section 2, we propose the feature(principal direction) extraction method. In section 3, an improved LIC algorithm is introduced to transfer the feature vector volume into a stroke based scale volume. By inserting the stroke into the original volume, we can implement the rendering of the whole information. Some examples will be shown in section 4.

## 2. Feature Extraction

### 2.1. Terms and Definition

Given any point on one smooth surface, there exists a direction on which the curvature of the surface is the greatest. The direction is called as the *principal direction* at this point.

In the partial volume, each voxel is represented as a mixture of several objects. For each object in a voxel, it is connected with a percentage value. Thus, we can define this type of voxel as “mixel”, which means “mixture voxel”. As defined above, each mixel  $M_{i,j,k}$  is represented as a set of percentage values shown as following :

$$M_{i,j,k} = \left\{ \left\langle P_{i,j,k}^1, P_{i,j,k}^2, \dots, P_{i,j,k}^m \right\rangle \middle| \sum_{t=1}^m P_{i,j,k}^t \leq 1.0 \right\} \quad (1)$$

In the equation (1),  $m$  means the maximum number of the objects.  $P^t$  means the percentage of object  $t$  in this mixel.

Given a mixel  $M_{i,j,k}$ , there are several objects in this mixel. Without losing generality, we choose object  $l$  as an example. As shown in equation,  $P_{i,j,k}^l$  is the percentage of object  $l$  in this mixel. So one or more iso-intensity surfaces can be constructed from the partial volume. Those iso-intensity surfaces go through the mixels whose percentage of object  $l$  is equal to  $P_{i,j,k}^l$ . Given the iso-intensity surface and the position  $(i, j, k)$ , we can calculate the principal direction at this position from the iso-intensity surface. This principal direction is defined as the principal direction of object  $l$  at position  $(i,j,k)$ ---  $v_{i,j,k}^l$ . Thus we can construct a new vector volume  $V$  from the original partial volume

$$V_{i,j,k} = \left\{ \left\langle v_{i,j,k}^1, v_{i,j,k}^2, \dots, v_{i,j,k}^m \right\rangle \right\} \quad (2)$$

Principal direction is an important attribute of 3D surface. A series of principal directions can describe the 3D shape clearly. So the vector volume stores all principal direction information for each object at any position, this volume is called as feature volume. Using the vector in this volume, we can track any iso-intensity surface shape and display it. From the variance of different isosurfaces, we can find some information concealed by the partial volume.

## 2.2. Extracting Principal Direction

Since we know that the principal direction is a useful feature to describe the partial volume, how to extract this principal direction? One method is to extract all iso-intensity surface and calculate the principal direction for each position. Apparently this method will consume lots of time and resource. In our algorithm, a direct extraction method is used. This method was introduced by Olivier Monga[9][10] first time, it can get the iso-intensity principal direction from 3D volume directly.

Suppose  $I(x,y,z)$  is a 3D data volume, the first partial derivative of this data can be gotten by Gaussian filter[9]. That is  $I_x(x,y,z)$ ,  $I_y(x,y,z)$ ,  $I_z(x,y,z)$ . this vector  $(I_x, I_y, I_z)$  is the normal direction of the iso-intensity surface at this point.

After getting the normal information, there exist a tangent plane which is perpendicular to the normal direction. The principal direction is the direction on this plane on which the curvature is maximum. Let  $a$  and  $b$  are two arbitrary orthogonal direction on the tangent plane. Then any direction on the plane can be represented as  $t = a \cos \beta + b \sin \beta$ . The principal direction should be:

$$\tan 2\beta = \frac{2a^T H b}{a^T H a - b^T H b} = E \Rightarrow (\beta_1 = \frac{\arctan E}{2}) \vee (\beta_2 = \beta_1 + \frac{\pi}{2}) \quad (3)$$

the corresponding curvature is

$$k = -\frac{t^T H t}{\|g\|} \quad (4)$$

In equation(3) and (4),  $g$  is the normal,  $H$  is the 3\*3 Hessian matrix:

$$H = \begin{bmatrix} I_{xx} & I_{xy} & I_{xz} \\ I_{yx} & I_{yy} & I_{yz} \\ I_{zx} & I_{zy} & I_{zz} \end{bmatrix} \quad (5)$$

In the Hessian matrix, all elements are the second derivatives calculated by Gaussian filter. We noticed from the equation(3) that there exists two possible result: By comparing the corresponding curvature, we can figure out the maximum which is principal direction; the denomination is zero. In the latter circumstance, this point is an umbilic point. That means that the curvatures are equal at any direction. We can mark this point and store the normal direction, this information will be used in following processing.

After calculate the principal direction at all position for all objects, the corresponding feature based vector volume is constructed. This volume not only record the principal direction information, but also store the shape information of the all available iso-intensity surfaces. These information will give me more understanding of the data.

## 3. Feature Based Rendering

Now we got two different volumes: one is scale volume - original partial volume, the other is a vector volume - principal direction volume. We not only need to retain the information of the original partial volume, but also need to display some useful information from the vector volume. To implement this goal, a two-step feature based rendering algorithm is used in this paper.

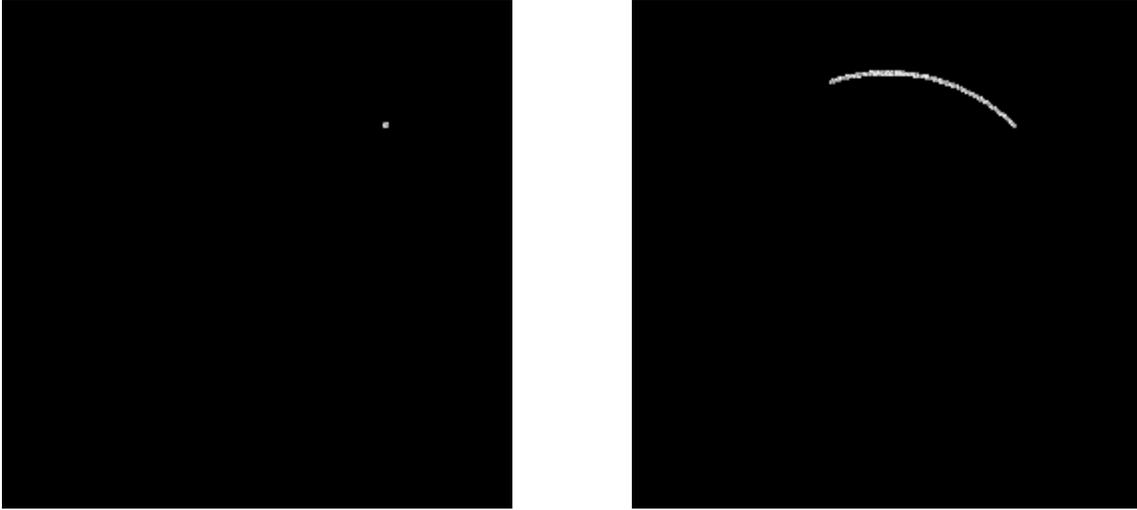
### 3.1. Improved LIC

LIC algorithm[8] is one of the most popular algorithms to render the vector volume. It is a visualization technique that synthesizes texture images from the input vector volume. The core equation of this technique is

$$I(x_0) = \int_{t=x_0-L}^{x_0+L} T(t)k(t-x_0)dt \quad \text{or} \quad I(x_0) = \sum_{t=0}^L T(\lfloor p_i \rfloor)k(t)h_i + \sum_{t=0}^{-L} T(\lfloor p_i \rfloor)k(t)h_i \quad (6)$$

By convoluting the input texture image along a path defined by the vector, LIC output a synthesized texture whose pattern can reflect the whole distribution and current of the vector field.

Discarding the white noise texture images used in traditional LIC algorithm, we use a texture image which only contains some distributed seed blocks(Figure 1). The distribution of these clusters are well designed. Using the principal direction volume and this special input texture, a special sparse stroke volume is created. In this volume, all principle directions are converted to several sparse strokes. Thus the surface information is converted into the volume information. By controlling the distribution of the seed points and the other attributes of the LIC algorithm, different stroke volumes can be generated in which different interesting feature sections are focused at different “directions”.



**Figure 1.** The seed block in input texture image(left); the result stroke constructed by LIC(right)

As we described in section 2.2, at some point there is no principal direction. Thus when stroke arrives this point , there is no a definite direction to go on. It will shorten the stroke length, and make it hard to reflect the whole vector field. We modified the LIC algorithm when the stroke meets such point. Suppose  $V_{input}$  is the direction of the stroke when he meet the umbilic point. Because this point is marked, we can get the normal direction  $N$ . So we can calculate the temporary principal direction at this point  $V_{output}$ .

$$V_{output} = (1-t) \cdot N + t * V_{input} \quad t = (N \bullet V_{input}) \quad (7)$$

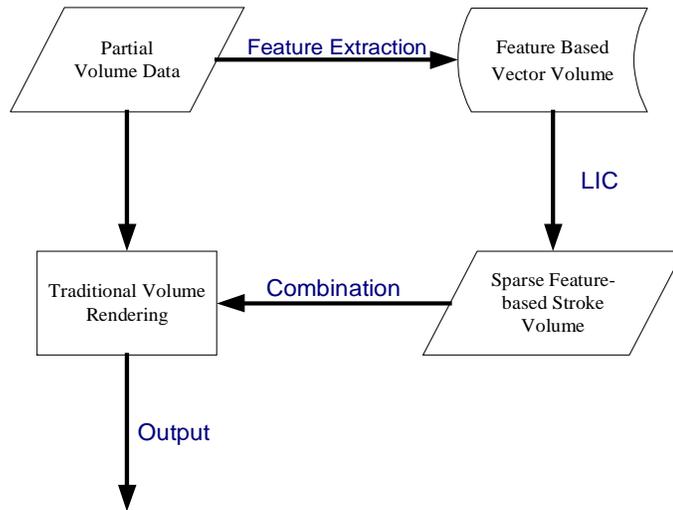
The  $V_{output}$  gotten from equation(7) lies on the tangent plane, and the angle between it and  $V_{input}$  is minimum.

### 3.2. Invoking the Stroke

Since there are two scale volume: the original partial volume  $I$  and the sparse stroke volume  $S$ , the combination need to be done. To do so, we can ensure that the final volume not only contain the partial information, but also contain the stroke information that reflect the inner variance in the partial volume. The whole combination is done as follows:

$$I^m(x, y, z) = \begin{cases} I^m(x, y, z) & S^m(x, y, z) = 0 \\ S^m(x, y, z) \oplus I^m(x, y, z) & S^m(x, y, z) \neq 0 \end{cases} \quad (8)$$

In equation (8),  $m$  indicates the object. Because the stroke volume is a sparse stroke volume, the strokes distribute in the interesting region, the combination will not affect our observation of the whole data. Furthermore, we can learn more by the stroke distributed in specific region(see Figure 3). The whole algorithm can be described in Figure 2.



**Figure 2.** The flowchart of our rendering algorithm.

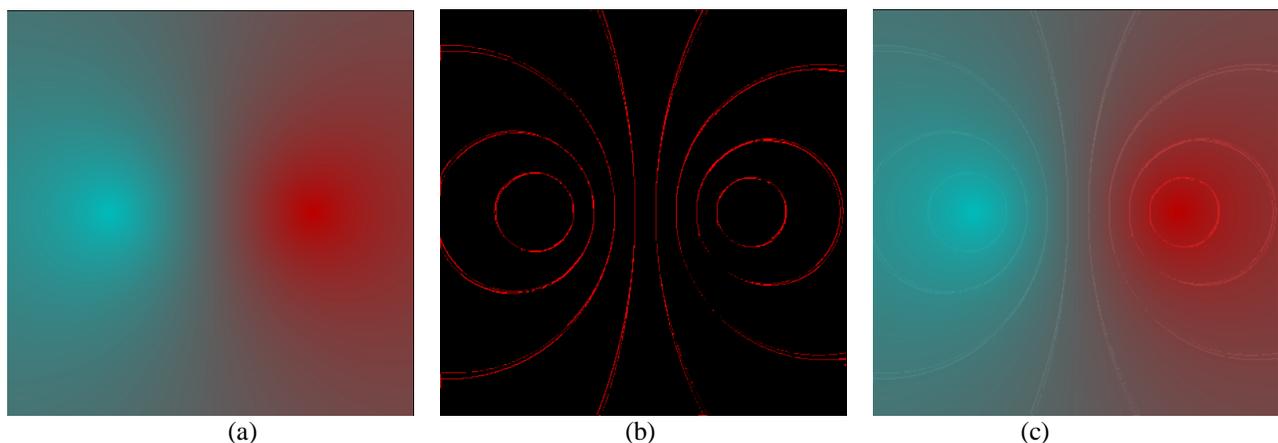
## 4. Experiments and Results

The whole feature based rendering algorithm showed in this paper was implemented in Visual C++ on PC. We used constant function as the kernel function of the LIC algorithm. The distribution of the seed cluster is made by random distribution.

Figure3 shows the example of 2D partial image. In this example, there is two objects(object 1's color is red). In each pixel, the percentage of the object is calculate as :

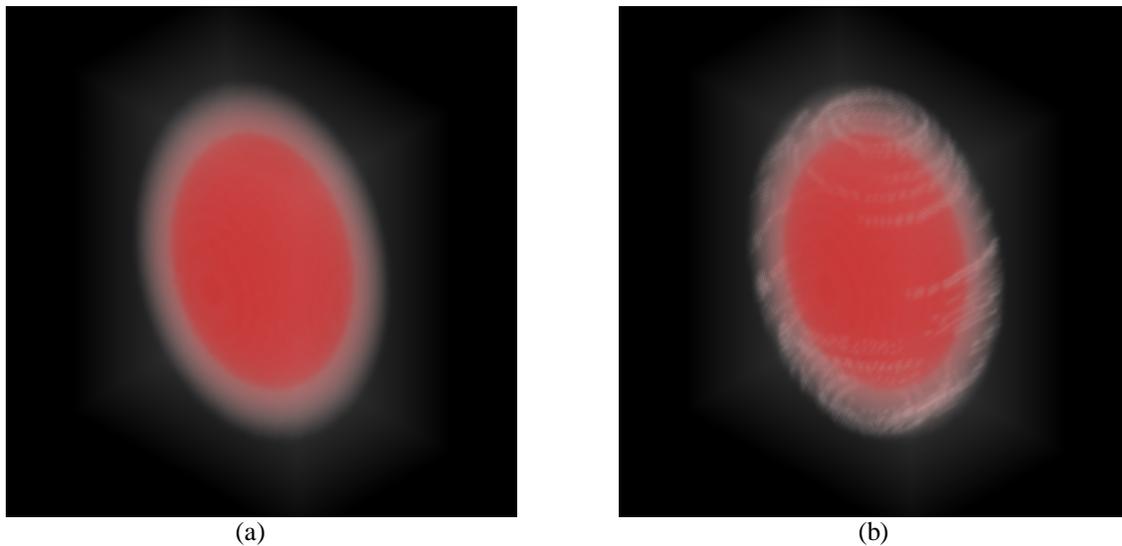
$$P^1(x, y, z) = \frac{Dis^2(x, y, z)}{Dis^1(x, y, z) + Dis^2(x, y, z)} \quad P^2(x, y, z) = \frac{Dis^1(x, y, z)}{Dis^1(x, y, z) + Dis^2(x, y, z)}$$

The  $Dis^m$  function is to compute the distance from current position to the center of object  $m$ . In figure 3(a), we can see the original dataset, it is rendered by the traditional rendering. Figure(b) is the sparse feature based stroke, we chose several layer to be rendered, so we can only see several long stroke. The final combination is shown in figure(c). Both the original object and stroke is clear in this image.



**Figure 3.** (a) The original 2D partial volume image. (b) The sparse feature based stroke image (only selected layer). And (c) the combination rendering result

The other example is a 3D elliptical sphere. There still exist two objects in this volume: the inner is the object 1 (red); the outer is the white. All images are rendered by volume rendering. As shown in figure 4(a), the original rendering image without stroke just give me an outline of two objects. But the shape is clear in figure 4(b) after invoking the stroke into it.



**Figure 4.** (a) The original 3D partial volume image. (b) The rendering result with feature extracted from the partial volume image data.

## 5. Conclusion and Future Works

One of the features in the partial volume segmentation dataset is the principal direction. For each element in the partial volume dataset, there exists an iso-intensity contour/surface across through that element volume. This principal direction represents the link between the adjacent elements with the same percentage. By collecting all the directional information, a corresponding feature-based vector volume is then constructed. This volume contains one of the most important features of the partial volume dataset. From this feature (principal direction) vector volume, an improved line integral convolution (LIC) algorithm is developed to construct a feature-based sparse stroke volume. In this feature-based sparse stroke volume, all principle directions are converted to several sparse strokes. Thus the surface information is converted into the volume information. By controlling the distribution of the seed points and the other attributes of the LIC algorithm, different stroke volumes can be generated in which different interesting feature sections are focused at different “directions”.

Combining the feature-based sparse stroke volume within the traditional volume based rendering procedure, the feature-based strokes can be integrated into the traditional rendering. Besides the inner information of the partial volume dataset provided by volumetric rendering, we can also visualize the features simultaneously. These features can enhance the detail which could be overlooked in the traditional volumetric rendering or could not be observed in the traditional surface rendering.

Although this techniques can extract the principal direction and show it, the method is not perfect at all circumstance. It is much suitable for the smoothly variance field. When the variance of the percentage is not smooth, the result may be not as good. This is also the future work we try to continue our research on.

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