3D Reconstruction from X-ray Fluoroscopy for Clinical Veterinary Medicine using Differential Volume Rendering

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Keywords: Fluoroscopy, Volume rendering, Veterinary Medicine, 3D reconstruction, Computerized Tomography

3D reconstruction from ordinary X-ray equipment which is not CT or MRI is required in clinical veterinary medicine. Authors have already proposed a 3D reconstruction technique from X-ray photograph to present bone structure. Although the reconstruction is useful for veterinary medicine, the technique has two problems. One is about exposure of X-ray and the other is about data acquisition process. An x-ray equipment which is not special one but can solve the problems is X-ray fluoroscopy. Therefore, in this paper, we propose a method for 3D-reconstruction from X-ray fluoroscopy. Fluoroscopy is usually used to observe a movement of organ or to identify a position of organ for surgery. Since fluoroscopy can output a observed result as movie, the previous two problems which are caused by use of X-ray photograph can be solved. However, a new problem arises due to weak X-ray intensity. Although fluoroscopy can present information of not only bone structure but soft tissues, the contrast is very low and it is very difficult to recognize some soft tissues. To solve this problem, this paper proposes a new method to determine opacity in volume rendering process. The opacity is determined according to 3D differential coefficient of 3D reconstruction. This differential volume rendering can present a 3D structure image of multiple organs volumetrically and clearly. This paper shows results of simulation and experimental investigation of small dog and evaluation by veterinarians.

1. 3D Reconstruction from Fluoroscopy
The reconstruction process is as follows:
(1) Fluoroscopy movie is taken with rotation of a object or system.
(2) The movie is divided into frame images.
(3) If angular velocity of the rotation and the number of frame images per second are known, view angle of each frame image is identified.
(4) 90 frame images are picked up every 2 degree in view angle to reconstruct 3D image.
(5) 1D Gray level profile is extracted from all pre-processed image at the same row.
(6) 2D slice image is reconstructed by Fourier Domain Reconstruction (FDR) from a set of 1D gray level profile every row.
(7) 3D voxel data set is constructed from a set of 2D slice image.

2. Differential Volume Rendering
Opacity is determined according to 3D differential coefficient for each voxel to enhance tissue boundary in volume rendering image.

3. Simulation Result
The proposed method is investigated in simulation. Fig.1(a) is human body model. The gray levels correspond to X-ray absorption coefficients of soft tissues. Fig.1(b) is by conventional volume rendering and Fig.1(c) is by the proposed differential volume rendering. Fig.1(c) shows better quality of image where 3 soft tissues can be recognized.

4. Experimental Result
The proposed method is applied to practical fluoroscopy which is about small dog. The fluoroscopy is shown in Fig.2(a). Fig.2(a) is an example of frame image. 90 frame images are extracted from the fluoroscopy and 3D reconstruction (3D data set) is obtained. Fig.2(b) and (c) shows volume rendering image. Fig.2(b) is by conventional one and Fig.2(c) is by the proposed one.

5. Conclusions
This paper proposes a new 3D reconstruction and display method from fluoroscopy using differential volume rendering for clinical veterinary medicine. The results show the objective is accomplished. Automatic opacity setting and tumor and lesions imaging are remained as future work.
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3D reconstruction from ordinary X-ray equipment which is not CT or MRI is required in clinical veterinary medicine. Authors have already proposed a 3D reconstruction technique from X-ray photograph to present bone structure. Although the reconstruction is useful for veterinary medicine, the technique has two problems. One is about exposure of X-ray and the other is about data acquisition process. An x-ray equipment which is not special one but can solve the problems is X-ray fluoroscopy. Therefore, in this paper, we propose a method for 3D-reconstruction from X-ray fluoroscopy for clinical veterinary medicine. Fluoroscopy is usually used to observe a movement of organ or to identify a position of organ for surgery by weak X-ray intensity. Since fluoroscopy can output a observed result as movie, the previous two problems which are caused by use of X-ray photograph can be solved. However, a new problem arises due to weak X-ray intensity. Although fluoroscopy can present information of not only bone structure but soft tissues, the contrast is very low and it is very difficult to recognize some soft tissues. It is very useful to be able to observe not only bone structure but soft tissues clearly by ordinary X-ray equipment in the field of clinical veterinary medicine. To solve this problem, this paper proposes a new method to determine opacity in volume rendering process. The opacity is determined according to 3D differential coefficient of 3D reconstruction. This differential volume rendering can present a 3D structure image of multiple organs volumetrically and clearly for clinical veterinary medicine. This paper shows results of simulation and experimental investigation of small dog and evaluation by veterinarians.

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1. Introduction

X-ray medical examination technique is indispensable and widely applied. Especially, 3D reconstruction is useful to observe 3D structure of organs directly. 3D reconstruction can be usually got by Computerized Tomography (CT) technique.

3D reconstruction is certainly useful in the field of clinical veterinary medicine. Unfortunately, however, CT equipment cannot be used in clinical veterinary medicine. It is usual that X-ray car visits, for example, a dairy farmer and X-ray photographs of an industrial animal which is horse or cattle, etc are taken. In the case of economic animal, which is dog or cat, etc., an expensive medical equipment such as CT cannot be equipped since a unit price of medical examination for economic animal has to be decreased. Therefore, 3D reconstruction from ordinary X-ray equipment which is low cost and small size, and is not CT or MRI is strongly required in clinical veterinary medicine.

Authors have already proposed a 3D reconstruction technique from X-ray photograph to present bone structure for clinical veterinary medicine (1). The technique uses 12 X-ray photographs (roentgen images) which are taken around object every 15 degree. Although the reconstruction is useful for veterinary medicine, the technique has two problems. One is about exposure of X-ray and the other is about data acquisition process. The amount of X-ray is large and dangerous when 12 roentgen images are taken. In addition to it, there is a problem where positioning of X-ray film is changed whenever roentgen image is taken. The problem requires very complicated pre-process to identify the same slice level and position in all images.

An x-ray equipment which is not special one but can solve the problems is X-ray fluoroscopy. Therefore, in this paper, we propose a method for 3D-reconstruction from X-ray fluoroscopy for clinical veterinary medicine. Fluoroscopy usually uses to observe a movement of organ or to identify a position of organ for surgery. Therefore, its objective is to present not only bone structure but soft tissues clearly by ordinary X-ray equipment in the field of clinical veterinary medicine. There are some examples where fluoroscopy or similar system has been used for 3D reconstruction(2)(3). However, ref.(2) uses prior-knowledge of an object and the object is limited to angiography and ref.(3) uses very large scale X-ray equipment. They are different from the proposed method in this paper.

Since fluoroscopy can output a observed result as movie, the previous two problems which are caused by use of X-ray photograph can be solved. However, a new problem arises due to weak X-ray intensity. The problem is about contrast due to small difference among X-ray absorption coefficients of soft tissues. Although fluoroscopy can present information of not only bone structure but soft tissues, the contrast is very low and not quantitative, and it is very difficult to recognize some soft tissues.

To solve this problem, this paper proposes a new method to determine an opacity in volume rendering process. The opacity is determined according to 3D differential coefficient of 3D reconstruction. This differential volume rendering can present a
3D structure image of multiple organs volumetrically and clearly. This paper shows 3D reconstruction results of simulation and experimental investigation of small dog and the evaluation by veterinarians.

2. 3D Reconstruction from X-ray Fluoroscopy

2.1 Pre-process Although 3D Reconstruction from X-ray photograph (roentgen image) is useful for veterinary medicine, some problems arise in the reconstruction process, especially, data acquisition process. Since positionings of X-ray film every taking photograph are all different, very complicated pre-process is needed to identify a rotation axis and the same slice level(3).

In this paper, a new data acquisition method is proposed by using fluoroscopy. The relation between X-ray source (transmission side) and X-ray detector (receiving side) is fixed in fluoroscopy case. The positioning problem such as roentgen image case is not caused. The new pre-process is as follows:

1. Fluoroscopy movie is taken with rotation of a object or system.
2. The movie is divided into frame images.
3. If angular velocity of the rotation and the number of frame images per second are known, view angle of each frame image is identified.
4. 90 frame images are picked up every 2 degree in view angle to reconstruct 3D image.

Since X-ray intensity of fluoroscopy is lower than one of roentgen system, the interval angle of view is smaller than angle to reconstruct 3D image. It can bring better quality of reconstruction.

2.2 3D Reconstruction After the pre-process, the reconstruction process is proceeded to 2D slice reconstruction and 3D reconstruction. Actually, these processes are the same as ref.(1).

1D gray level profile is extracted from all pre-processed image at the same row. The profile can be assumed to projection data of CT. 2D slice image is reconstructed by Fourier Domain Reconstruction (FDR)(4) from a set of 1D gray level profile every row.

3D voxel data set is constructed from a set of 2D slice image. The set means 3D reconstruction.

3. Volume Rendering Algorithms

There are some rendering methods to render 3D data set to 2D screen. In ref.(1), since the objective was bone structure presentation from roentgen image, iso-surface method was used.

On the other hand, fluoroscopy is used in this case. Fluoroscopy can present not only bone structure but some soft tissues. It is another useful advantage of fluoroscopy to be able to observe not only bone structure but soft tissues in the field of clinical veterinary medicine. Therefore, a method which can present multiple organ in a 2D image on 2D screen is better than iso-surface method. The method which enables to do the presentation is volume rendering.

Volume rendering technique represents a 3D object value on 2D screen as a collection of voxel values with opacity for each voxel along the ray from view point to the 3D object. Volume rendering enables to present the 3D object on 2D screen volumetrically.

3.1 Basic Volume Rendering The concept of basic volume rendering technique is based on the same opacity for all voxels. Fig.1 shows the relationship among viewpoint, 2D screen, a ray, voxels on the ray and 3D object. We can calculate a gray value of a pixel on corresponding coordinates on 2D screen from voxel values on a ray between view point and 3D object by using standard transparency formula as equation (1).

The basic volume rendering equation:

\[ G_z = g_z \times \text{opa} - 1 \text{, } z = 1,2,3, \ldots \]

where

- \( G_z \): Rendering gray value to coordinate along the ray
- \( g_z \): Voxel value on coordinate along the ray
- \( \text{opa} \): Opacity

3.2 Proposed Volume Rendering Fluoroscopy can display soft tissues, but the contrast is low and gray value is not quantitative. Because absorption coefficients for each soft tissue are the approximately same. The feature causes a blurred 2D slice image. As the result, it is supposed that it is very difficult to recognize multiple soft tissues in volume rendering image. To enhance difference between multiple tissues and to enable to recognize them, a new method to determine opacity is proposed.

The method is differential volume rendering where the opacity is determined according to 3D differential coefficient to enhance a boundary of soft tissue.

3D differential coefficient is used in volume rendering process in ref.(5). However, the coefficient is used for only enhancement of edge of boundary of tissue. Opacity is determined according to CT value. In proposed method, Opacity is determined according to 3D differential coefficient. In the case of 3D reconstruction from fluoroscopy, the gray value is not quantitative. Therefore, opacity cannot be determined by the gray value. The basic idea of proposed method is “a position where the difference of gray values is large is a boundary of tissue”. Setting opacity according to the difference, that is to say, 3D differential coefficient can bring a volume rendered image where the boundaries (structure of organs) are shown volumetrically. This proposed method is obviously different from previous ones, especially, ref.5 and very useful for clinical veterinary medicine in which 3D image has to...
be shown from non-quantitative data.

The proposed process is as follows:

1. A voxel value is differentiated in regard to x-y plane, x-z plane and y-z plane respectively. 3 differential coefficients are obtained. Prewitt is used as differential filter.

2. Summation of 3 absolute values of differential coefficients is defined as 3D differential coefficient, $A(x,y,z)$. Although norm may be usually used in such case, this expression is also used frequently as simple case in image processing\(^{(6)(7)}\).

3. Opacity for each voxel, $opa(x,y,z)$ is determined from $A(x,y,z)$ by following process.

$$
\text{If } A(x,y,z) > \text{diff}_{\text{base}} \\
\text{If } A(x,y,z) > \text{diff}_{\text{max}} \\
\text{If } A(x,y,z) > \text{diff}_{\text{max}} \\
\text{else} \\
opa(x,y,z) = 0 \\
\text{else} \\
opabase \times \frac{A(x,y,z)}{\text{diff}_{\text{base}}} \\
\text{else} \\
opabase \times \frac{A(x,y,z)}{\text{diff}_{\text{base}}}
$$

In this process, $\text{diff}_{\text{base}}$ and $\text{diff}_{\text{max}}$ are constants for 3D differential coefficient defined by user to control the range of gray level to display. $\text{opa}_{\text{base}}$ is standard opacity and also defined by user for $\text{diff}_{\text{base}}$. User can control the range of gray level to display and can select any target tissue to see by adjusting these 3 parameters.

The larger 3D differential coefficient is, the greater the possibility that the position is a boundary of tissue is. Therefore, opacity is larger when 3D differential coefficient is larger. On the other hand, when 3D differential coefficient is lower, a decision to make whether the position is a boudary or not is entrusted to a veterinarian. If a veterinarian decide that the position is not boundary, $\text{diff}_{\text{base}}$ is set to smaller value (large difference between $\text{diff}_{\text{max}}$ and $\text{diff}_{\text{base}}$) or $\text{opa}_{\text{base}}$ is set to smaller value. By this operation, only regions where 3D differential coefficient is larger are displayed. A region where 3D differential coefficient is the largest is usually outside boundary (outside surface). If opacity for outside boundary is large, inside objects cannot be seen. Therefore, $\text{diff}_{\text{max}}$ is defined to avoid the influence. When $\text{diff}_{\text{max}}$ is set to smaller value and $\text{opa}_{\text{base}}$ is set to larger one, regions where 3D differential coefficient is lower is displayed. If the difference between $\text{diff}_{\text{max}}$ and $\text{diff}_{\text{base}}$ is smaller and $\text{diff}_{\text{max}}$ is larger, all of boundary and supposed boundary are displayed simultaneously in the approximately same brightness. In the case where the difference between $\text{diff}_{\text{max}}$ and $\text{diff}_{\text{base}}$ is constant, if $\text{opa}_{\text{base}}$ is set to larger value, not only regions where 3D differential coefficient is larger but regions where the coefficient is smaller are displayed.

Volume rendering equation is as follows:

$$
G_z = g_z \times \text{opa}(x,y,0) \\
G_z = G_z \times (1 - \text{opa}(x,y,z)) + g_z \times \text{opa}(x,y,z) \quad z=1,2,3, \ldots, z
$$

Figure 2. 3D human model on x-y plane at the center of the model.

(a) basicmethod (b) proposed method

Figure 3. Comparison between conventional and proposed method.

Figure 4. differential volume rendering image in the case of lower $\text{diff}_{\text{max}}$ than Fig.3(b).
rendering. \( \text{diffbase} \) is 30, \( \text{opabase} \) is 0.01 and \( \text{diffmax} \) is 500. Although bottom sphere, B can be recognized with difficulty, upper 2 spheres, D and C cannot be seen in Fig.3(a). On the other hand, not only B but D and C can be observed in Fig.3(b).

We also evaluate the influence of \( \text{diffmax} \). Fig.4 shows the case where \( \text{diffbase} \) is 30, \( \text{opabase} \) is 0.01 and \( \text{diffmax} \) is 300. As the \( \text{diffmax} \) is set to lower value, the range of visualization becomes narrow. The narrow range can be expanded and displayed in 0-255 gray level on 2D screen. Therefore, when a sphere’s differential coefficient is in the range, the sphere can be displayed more clearly. It is slight difference but spheres B, D and C in Fig.4 can be displayed more clearly, in higher contrast compared with Fig.3(b).

If a differential coefficient is over \( \text{diffmax} \), the object (tissue) becomes transparent, so it also becomes invisible one on 2D screen.

5. Experimental Results

5.1 3D Reconstruction

The proposed technique is applied to practical fluoroscopy. A example of 2D frame image extracted from fluoroscopy is shown in Fig.5.

In this experiment, point X-ray source is used. However, since the object (small dog) is small and enough distance between the source and the object is kept, X-ray beam is assumed to be parallel and fine beam. The dog is covered with urethane foam and fixed in a pipe made of cardboard after anesthesia. The position revision in the case of ref.1 is not needed in the case of fluoroscopy.

This fluoroscopy was taken regarding a dog, abdominal region in 30[fps]. In this case, X-ray tube and detector are fixed and the dog is rotated. Back bone and rib bone structure and the bowels can be observed. The contrast for the bowels is higher than bone region. It is caused by gas in the bowels. The gas works as contrast agent.

![Fig. 5. An example of 2D frame image from fluoroscopy of abdominal region of a dog.](image)

![Fig. 6. Examples of 2D slice image reconstructed from fluoroscopy.](image)

![Fig. 7. 2D view by basic volume rendering.](image)

![Fig. 8. The proposed differential volume rendering image. Parameters are set to view the bowels structure.](image)

![Fig. 9. An image in the case where \( \text{opabase} \) is larger (0.05) than fig.8 case and each of \( \text{diffmax} \) and \( \text{diffbase} \) is the same as those in fig.8. Not only bowels structure but back bone structure can be seen.](image)
90 frames are extracted every 2 degree and 293 slice images are reconstructed. Examples of slice image are shown in Fig.6.

293 slice images are layered. The set of slice images is 3D reconstruction data set.

Basic volume Rendering image is shown in Fig.7. In Fig.7, opacity is uniform and the value is 0.3. A part of back bone and a part of bowels are displayed but both of them are not complete and the quality is not required level. They are very blurred and some small structures cannot be displayed.

Fig.8 shows the proposed differential volume rendering image. Median filter is used for noise reduction before 3D differentiation. It is an image in the case where the range is set to bowels only. In Fig.8, $\text{diff}_{\text{base}}$ is set to 600 and $\text{opa}_{\text{base}}$ is set to 0.04. $\text{diff}_{\text{max}}$ is set to omit outside boundary which has higher differential coefficient than soft tissue. Fig.8 shows only the bowels structure. The quality is clearer than Fig.7 in viewpoints of sharpness and small structure expression.

Fig.8 shows the case of larger $\text{opa}_{\text{base}}$ (0.05). Each of $\text{diff}_{\text{max}}$ and $\text{diff}_{\text{base}}$ is the same as those in fig.8. As mentioned in 3.2, not only bowels structure but bone structure is displayed. In this case, differential value for bone is smaller than one for bowels. This result shows user can control the range of gray level to display and select tissues which user wants to display.

5.2 Evaluation by Veterinarians These experimental results are evaluated by 2 veterinarians. The evaluation is as follows:

- Structure of intestinal canal is displayed clearly and its positioning can be understood in 3 dimension. The image is more effective than X-ray photograph.
- In fig.9, the relationship between several organs’ positioning can be seen. It is one of the most important information which veterinarian wants to know.
- If this image and X-ray photograph with contrast agent are used together, it is more effective, especially, for surgical operation.
- A foreign bodies in intestines or tumor especially, malignant tumor should be displayed in the future work.

6. Conclusions

3D reconstruction and display technique using differential volume rendering technique for clinical veterinary medicine is proposed.

3D reconstruction method by ordinary X-ray equipment is required in the field of veterinary medicine. Use of X-ray photograph (roentgen image) has been proposed but the method requests very complicated pre-process and has X-ray exposure problem. Therefore, this paper proposes the use of fluoroscopy. Since fluoroscopy uses weak intensity of X-ray and the relationship of a positioning between X-ray source and detector is solved.

Unfortunately, however, a new problem arises, which is about blurred image quality due to weak intensity of X-ray. Fluoroscopy can obtain information of soft tissues. Although it is another advantage of use of fluoroscopy to be able to display not only bone structure but soft tissues in the field of clinical veterinary medicine, X-ray absorption coefficients of soft tissues are the approximately same. Therefore, some soft tissues cannot be distinguished. In this paper, to distinguish multiple soft tissues in 3D expression from fluoroscopy, an effective volume rendering method for clinical veterinary medicine is developed, which is differential volume rendering.

The ability of the differential volume rendering is investigated in simulation and experiment of small dog. The results show the proposed method can display 3D structure of soft tissue more clearly than basic volume rendering method. User can control the range of gray level to display and select tissues which user wants to see by adjusting 3 parameters in the proposed volume rendering technique. In addition, the results are evaluated by 2 veterinarians. The evaluations say the proposed method has high ability to display 3D structure clearly and the 3D image is useful for surgical operation in clinical veterinary medicine.

As the result, 3D reconstruction from fluoroscopy in the field of clinical veterinary medicine is accomplished.

In the future there remain to investigate a method to determine the parameters automatically and to display a lesion, for example, malignant tumor or foreign bodies.

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References


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