Automatic construction of internal organs segmentation from PET image data using 3D-ACTIT

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***Abstract* — In the field of medical image processing, 3D(three dimensional) image processing is often required to deal with MRI, CT and PET image data. In general, however, it is not easy to construct complex 3D processing procedures manually compared with 2D ones. Thus, we propose a new method named "3D-ACTIT; Automatic Construction of Tree-structural Image Transformation" to make various 3D image processing procedures based upon example learning. ACTIT is the system that we previously proposed for automatic construction of 2D image processing[1][2]. ACTIT learns from several image processing example sets of original images and their target ones, and it approximates a target image processing with a tree whose non-terminals and terminals are typical image filters and input images, respectively according to Genetic Programming[3][4]. In this paper, we improve the ordinary ACTIT to 3D-ACTIT and apply it to several 3D test data and real PET image data. Experimental results show that various kinds of complex 3D image processing procedures can be constructed automatically by the proposed method.**

Ⅰ. Introduction

Today, many researches in image processing have been performed. Generally, we achieve to construct an image processing using pre-defined image processing filters. In this case, we are required a lot of knowledge and experiences about image processing. So, it is a difficult task to construct image processing.

Our research group previously proposed an image processing system named "ACTIT: Automatic Construction of Tree-Structural Image Transformation". This ACTIT system constructs tree-structured image processing filter from well-know filters prepared. We have applied ACTIT system to various image processings, confirmed that ACTIT system gets adequate image processing and effectiveness.

Recently, our research group focuses on medical image. In the field of medical image processing, 3D(three dimensional) image processing is often required to deal with Magnetic Resonance Imaging (MRI), Computed Tomography (CT) and Positron Emission Tomography (PET) image data. Various 3D image processing methods have been developed [5]. In general, however, it is not easy to construct complex 3D processing procedures manually compared with 2D ones. 3D image data also have larger amounts of data than that of 2D image data. Thus, in this paper, we improve the ordinary ACTIT to 3D-ACTIT in order to solve these problems.

Ⅱ. ACTIT and 3D-ACTIT

ACTIT system belongs to Evolutionary Image Processing[6] (image processing is solved as optimization problem using Evolutionary Algorithm.). This system can deal with many kinds of object. It is possible to improve ACTIT to 3D-ACTIT only by exchange ordinary 2D image processing filters for 3D ones and regard image data as voxel data. We can solve many problems of three dimensional image processing by using 3D-ACTIT.

A. Ordinary ACTIT

ACTIT constructs tree-structured image processing filter with well-known filters by using Genetic Programming to satisfy the given several image examples. We give "Training Image set", original image and its target image to ACTIT, this system constructs appropriate image processing automatically. We have solved many kinds of image processing problem by using ACTIT. For instance, ACTIT succeeded in extraction processing of cell wall and lung region segmentation.

B. Training image set of 3D-ACTIT

In medical image processing, many slice images are taken from a patient. From this example, 3D-ACTIT adopts regarding many slice images as a volume data set. 3D training image is composed of original slice images and their target images. In addition, it is possible to use multiple 3D training image sets.

C. Three-dimensional image processing filter

We exchanged two-dimensional image processing filters in ordinary ACTIT for three-dimensional ones. In 3D image processing, peculiar image processing filters have developed, for instance, enhancement filter. In this paper, we examined basic performance by using only typical filters.

D. Definition of fitness function

The fitness function is defined as

$$fitness = \frac{1}{K}\sum_{k=1}^{K}\left\{1-\frac{\sum_{x=1}^{W}\sum_{y=1}^{H}\sum_{z=1}^{D}\left|out_k(x,y,z)-trg_k(x,y,z)\right|}{\sum_{x=1}^{W}\sum_{y=1}^{H}\sum_{z=1}^{D}V_{\max}}\right\} \quad (1)$$

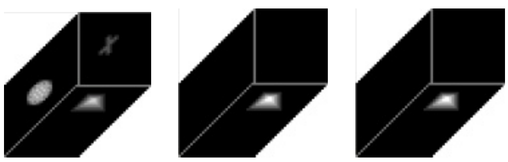
$out_k(x,y,z)$ is the transformed image and $trg_k(x,y,z)$ is its target one. The numbers of voxels in the direction x, y and z are W, H, D respectively, and the number of training image sets is K. fitness is calculated by the normalized summation of the distances between transformed and target image on every voxels.

Ⅲ. Experimental results

First, we made several test data to confirm operation of 3D-ACTIT. Next, we deal with real PET image data.

A. Experimental results of test image data

One of the test training image set and experimental results are shown in Fig.1.



(a) original (b) target (c) output

Fig.1 A training image set and output image of 3D-ACTIT

Fig.1, each image represents a 3D one constructed from 32 2D-images in a way illustrated in Fig.2.

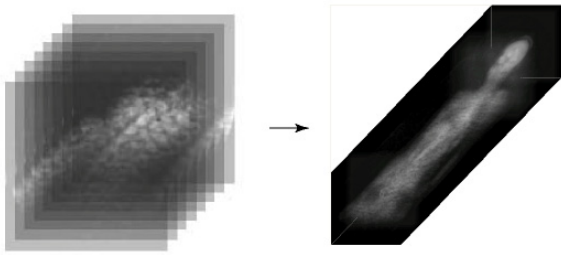


Fig.2 Indication of 3D image

Fig.1 is the training image set that extracts a only tetrahedral object from three different objects in three-dimensional space. Output image is same as target image. That is, required processing was obtained successfully. Moreover, we have obtained required processing in other objects. In other experiments, for instance, the processing of noise reduction has obtained by 3D-ACTIT.

Fig.3 shows the tree-structure which output Fig.1(c). In Fig.3, terminal node represents original image, non-terminal node represents 3D image processing filters, for instance, "M" is maximum filter and "m" is minimum filter. Fig.4(a) and (b) shows unknown image and output image that is applied the tree-structural filter of Fig.3 to unknown image. Output image shows that this process is successful. This result shows that it is possible to get tree-structural filter that applies to unknown image by 3D-ACTIT system.

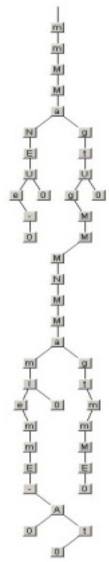


Fig.3
Tree-structure

(a) unknown image (b) output

Fig.4 Unknown image and output image

In other experiments, we obtained tree-structural filter that can apply to unknown image, so we confirmed basic operation and generality of 3D-ACTIT.

B. Application to real PET image data

Next, we made training image set of real PET image data, and experimented whether it is possible to apply 3D-ACTIT to real PET image data.

Fig.5 shows one of real PET slice image. Resolution of PET image is 128×128, and we cannot distinguish borderline of internal organs from it. Generally, it is difficult to construct image processing using conventional image processing method. We confirmed whether it is possible to apply 3D-ACTIT to PET image. Result of this experiment is shown in next section.

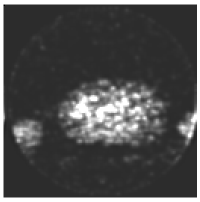
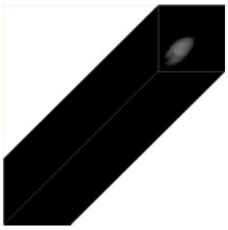


Fig.5 Real PET image

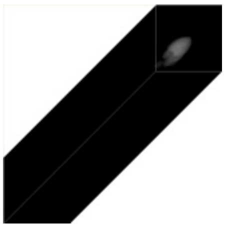
B-1. Extraction of brain

Original image data is constructed from 295 images. The purpose is to extract brain from original image shown in Fig.6.

(a) original image



(b) target image

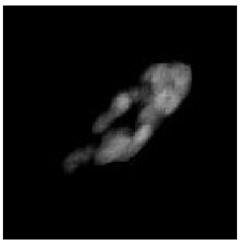


(c)output image

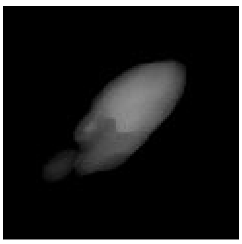
Fig.6 A training image set and output image of real PET data

Seeing Fig.6(b) and (c), you will see that output image is similar to target one.
On the other hand, we made Fig.7(a) manually so that it resembles to the target image. We employed maximum, minimum and binarization filter sequentially to make it. Fig.7(b) is output image of 3D-ACTIT. Comparing two images, you will consider that output of manual processing is not good result compare with that of 3D-ACTIT.

We can analyze the functions of the 3D filters step by step as demonstrated in Fig.8. This tree consists of two parts. One is the lower part of tree, which processes generally. The other part processes locally in higher of tree.



(a) manual processing



(b) 3D-ACTIT

Fig.7 Output of processing manually and that of 3D-ACTIT

Finally, the resultant image is output from the root node of the tree. Such processing is a general method in image processing. 3D-ACTIT system obtains such a processing procedure only given training image set. Moreover, processing procedure is general, but arrangement of filters is not the one that is quite hitting on.

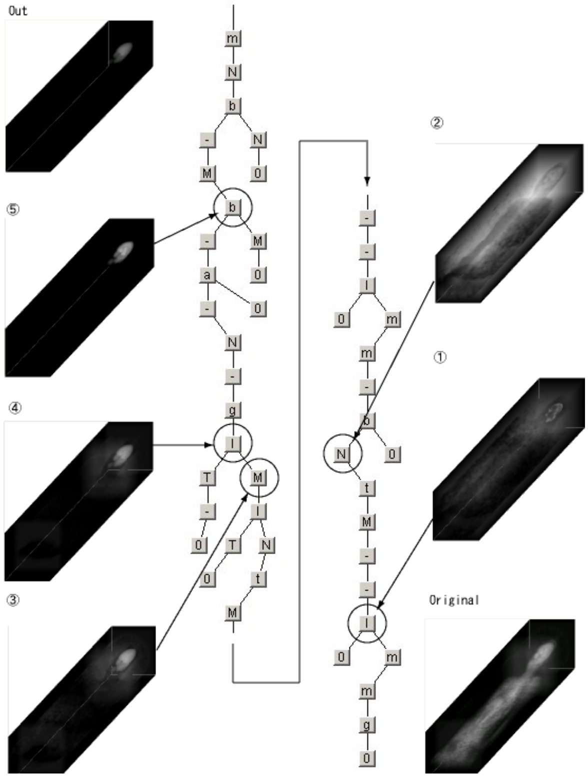
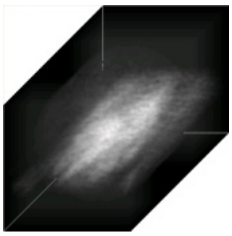


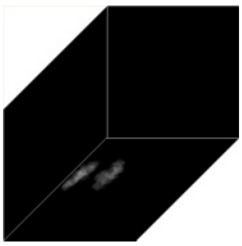
Fig.8 Tree-structure and its analysis

B-2. Extraction of kidney

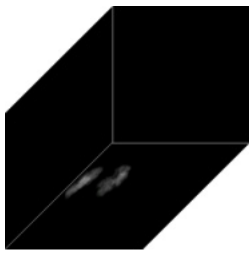
Fig.9 shows training image set in experiment on extraction of kidney. Seeing Fig.9(b) and (c), you will consider these two images are similar.



(a) Original image



(b) Target image



(c) Output image

Fig.9 A training image set and output image

Fig.10 is a PET image which contains kidney part. Processing of extraction of kidney is more complex than processing of extraction of brain, because kidney is enclosed by various internal organs. But 3D-ACTIT succeeded this processing.

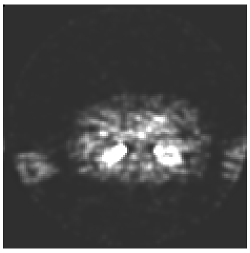


Fig.10 PET image which contains kidney

Tree-structure which is gat when experiment on kidney extraction is shown in Fig.11.

Seeing Fig.11, you will understand that this tree-structure has left and right part. The right part processes overall, the left part concentrates processing on kidney. Finally, these two parts are matched for bringing output image close to the target image.

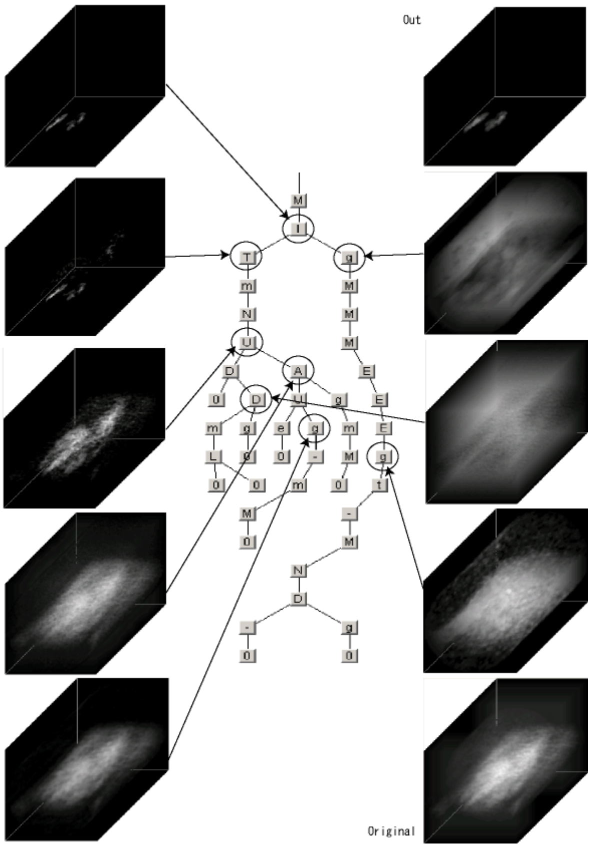


Fig.11 Tree-structure and its analysis

B-3. Extraction of liver

Fig.12 shows teaching image set in experiment on extraction of liver. In extraction of liver, accumulation of liver is lower than that of brain and kidney, so this process is more complex(Refer to Fig.13). Original image is the same as Fig.9(a).

(a) Target image (b) Output image

Fig.12 A training image set

Comparing target image with output image, you will see that these two images are very similar. The position of the liver is suitable, but the shape is not suitable. Fig.14 shows slice image of target and output.

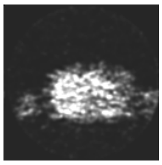


Fig.13 PET image contains liver

(a) target (b) output

Fig.14 Target image and output image

Fig.15 shows tree-structure which output Fig.12(b). This tree-structure is straight shape differ from Fig.9. This procedure looks like that of brain extraction.

We show Fig.16 to analyze the process shown in Fig.15 more precisely. Fig.16 is analysis using slice images. At first, seeing from lower part, shape of liver is extracted. But, in this step, other internal organs are extracted too. As the processing is advanced, only the liver is left gradually.

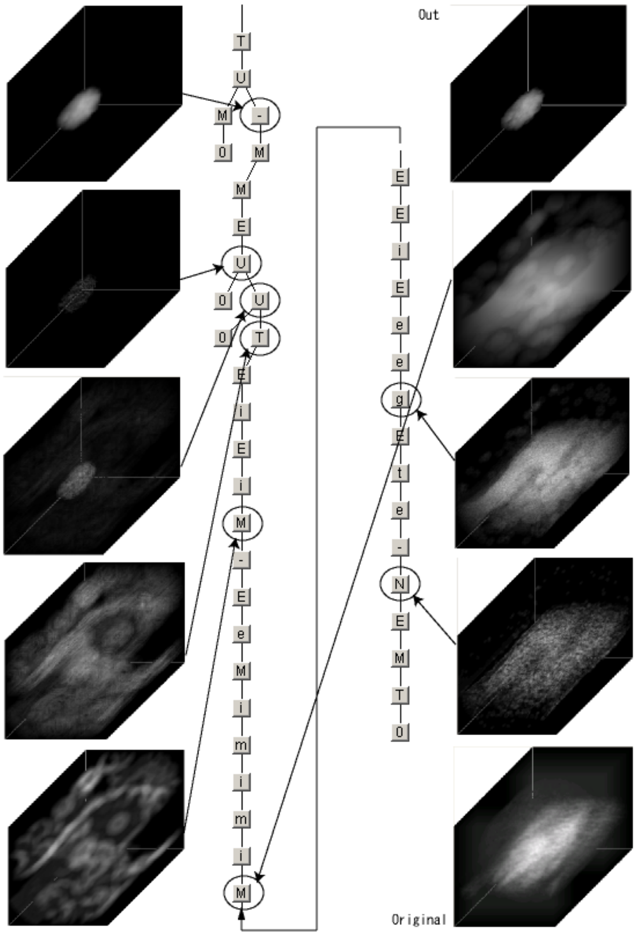


Fig.15 Tree-structure and its analysis

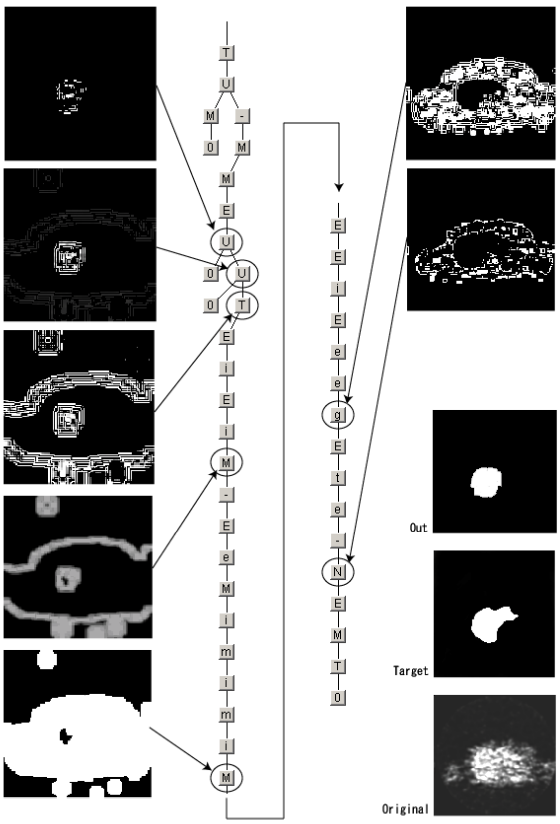


Fig.16 Tree-structure and its analysis
(all figures are 2D slice image)

We experimented on extraction of kidney and liver two or more times in the same PET image data. Fig.17 show the experimental result of extraction of liver, and Fig.18 is the tree-structure which output Fig.17.

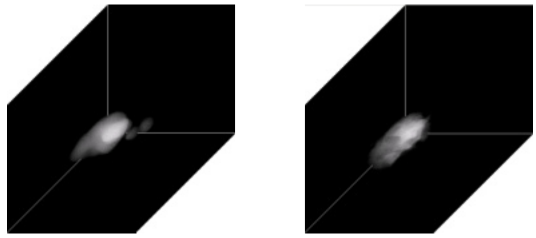


Fig.17 Output image

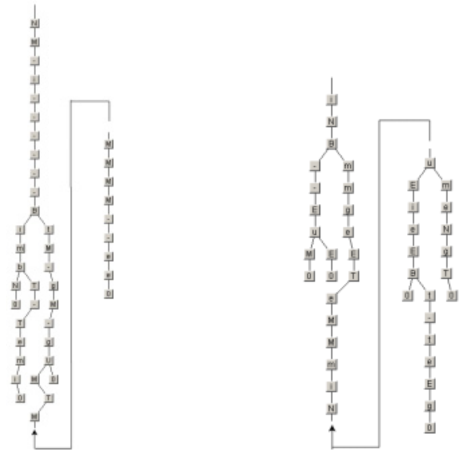


Fig.18 Tree-structure

Seeing Fig.17 and 18, you will see that these output images are similar and these tree-structures shape rough straight line. So, The processing of extracting liver has a certain feature. But, We cannot find the feature about the position of image processing filter. The analysis of tree-structure is necessary for us in the future.

Ⅳ.Experiment to different patient data

In section Ⅲ-B, this system used the PET image data which was taken by the same patient in each experiment. In this section, we show experimental results of applying 3D-ACTIT to other patient.

We made the training image set of extraction of kidney and liver from other patients' image data. Seeing Fig.19(a) and (b), these are slices of almost the same position, you will understand the difference of accumulation.

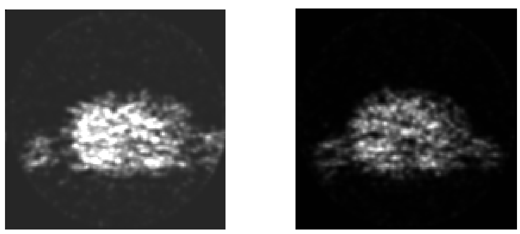
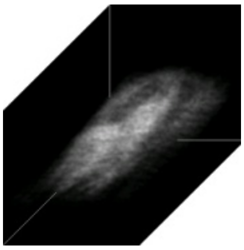


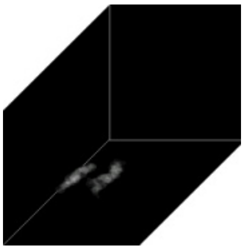
Fig.19 PET image of different patient

This difference is physiological. So, both of the images are normal examples.

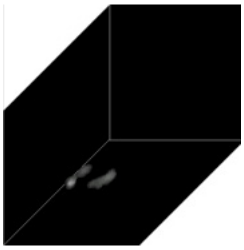
Fig.20 and 21 show training image set and output image in experiment on extraction of kidney and liver. We obtained similar result compared with section Ⅲ-B. It can be said that 3D-ACTIT demonstrated steady performance.



(a) Original image

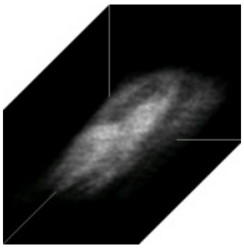


(b) Target image

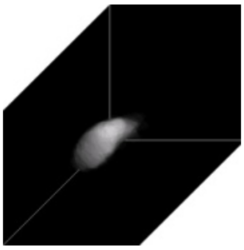


(c) Output image

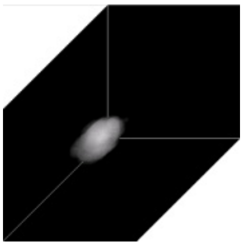
Fig.20 A training image set and output image



(a) Original image



(b) Target image



(c) Output image

Fig.21 A training image set and output image

Ⅳ. Conclusion and future works

We proposed 3D-ACTIT that can construct 3D image processing including medical processing from several samples. We verified the effectiveness of 3D-ACTIT in several experiments.

We are planning to apply 3D-ACTIT to extract other internal organs including liver, stomach and so on. And we are examining to use transcendental and medical knowledge, too.

Ⅴ. References

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