Three Dimensional Concentration Index
– A Local Feature for Analyzing Three Dimensional Digital Line Patterns and Its Application to Chest X-ray CT Images –

Yasushi Hirano
Graduate School of Eng., Nagoya Univ.
Nagoya 464-8603 Japan
hirano@toriwiki.niie.nagoya-u.ac.jp

Yoshito Mekada
Faculty of Eng., Utsunomiya Univ.
Utsunomiya 321-8585 Japan
mekada@infor.utsunomiya-u.ac.jp

Jun-ichi Hasegawa
School of Comp. and Cognitive Sciences,
Chukyo Univ.
Toyota 470-0393 Japan
hasegawa@sccs.chukyo-u.ac.jp

Jun-ichiro Toriwaki
Faculty of Eng., Nagoya Univ.
Nagoya 464-8603 Japan
toriwaki@niie.nagoya-u.ac.jp

Hironobu Ohmatsu
Div. of Thoracic,
National Cancer Center Hospital East
Kashiwa 277-0882 Japan
ohmatsu@east.ncc.go.jp

Kenji Eguchi
National Shikoku Cancer Center Hospital
Matsuyama 790-0007 Japan
keguchi@shikoku-cc.go.jp

Abstract

We propose a new local feature called three dimensional(3D) concentration index for analyzing line texture patterns in the 3D space. This feature can be used for evaluating quantitatively local concentration of lines at each point of a 3D line pattern. In the paper, simulations using artificial patterns is performed to examine basic properties of the index. The index is also applied to patterns of vessels and bronchi extracted from practical chest X-ray CT images. As a result, it is shown that 3D concentration index can be used to quantify the degree of convergence of vessels and bronchi to a tumor.

1. Introduction

The recent progress of X-ray CT scanners made it possible to generate precise three dimensional(3D) images which present the details of inner structure of a human body. Because this will cause the inflow of a large amount of 3D CT images to hospitals, computer-aided diagnosis of 3D CT images has been strongly required[1]-[4]. There are various researches on computer-aided diagnosis of lung diseases using 3D CT images. To classify lung tumors in a chest X-ray CT image into benign and malignant, quantitative criteria are needed. In particular, convergence of blood vessels and bronchi to a tumor is an important feature for diagnosis of the lung. But it is very difficult for medical doctors to evaluate the degree of such convergence quantitatively, because they must recognize and quantify the 3D structure from the set of two dimensional(2D) slice images. Therefore, if the convergence of blood vessels and bronchi can be quantified automatically from 3D CT images, the result will contribute much to lung diagnosis. No study has been reported, however, concerning the quantitative measure of the convergence.

In this paper, we define the 3D concentration index as a feature for quantification of local concentration of digital line patterns in 3D space and show its basic properties using artificial line patterns. Furthermore we apply it to practical CT images to show the effectiveness of the proposed index.

2. Definitions

The 2D version of the concentration index has been already proposed with application to cancer detection
from stomach X-ray images[6]. In this section we define the "3D concentration index" as a measure to evaluate the degree of local concentration in 3D line patterns, by extending the above 2D concentration index to the 3D space.

An input line pattern here is a 3D binary image. A voxel with the value 0 (1) is called a 0 (1)-voxel. First, each line in this input pattern is transformed into a set of short line segments called line elements, and then the 3D concentration index is calculated using line elements. We adopt definitions given in Ref.[5] concerning the concepts of digital geometry such as the neighborhood, the connectivity and the distance etc.

### 2.1. 3D line element

A line element is defined at every 1-voxel Q which satisfies both of the following two conditions(Figure 1).

(Condition 1) There are only two 1-voxels (Q<sub>1</sub>, Q<sub>2</sub>) in the 26-neighborhood of Q.

(Condition 2) The 26-neighbor distance between the above Q<sub>1</sub> and Q<sub>2</sub> is 2.

Note here that the notations Q, Q<sub>1</sub> and Q<sub>2</sub> present both the names of voxels and the names of their center points for the sake of convenience.

A few examples of line elements are shown in Figure 1. We assume that the center of the line element is on Q, that the direction of the line element is the same as that of the line segment Q<sub>1</sub>Q<sub>2</sub>, and that the length is the half of the length of Q<sub>1</sub>Q<sub>2</sub>.

### 2.2. 3D concentration index

The concentration index C(P) at an arbitrary voxel P in a 3D image is defined by the following equation,

\[
C(P) = \frac{\sum_{R} \frac{dse_{\alpha}}{r}}{\sum_{R} \frac{d}{r}} \tag{1}
\]

Assume that one of the line elements e<sub>l</sub> is defined on Q in the neighborhood region R as in Figure 2, d<sub>l</sub> is the length of e<sub>l</sub>, r is the length of PQ, and α is the angle between e<sub>l</sub> and PQ. Σ<sub>R</sub> means the summation over all line elements in the neighborhood region R which is defined as shown in Figure 2 in this paper. The reasons that we take such shape of R are 1) to avoid the influence of noisy line elements near the voxel P and 2) to avoid that 1/2 goes to infinite value in Eq.(1). The maximum and the minimum values of C(P) are 1 and 0, respectively. If there is no line element in R, we assume that C(P) takes the value 0 for the convenience' sake.

### 3. Basic properties

#### 3.1. Simulation with artificial patterns

The 3D concentration index was applied to artificial line patterns in order to know properties of the index C(P) defined above. Each pattern is a 301 × 301 × 301 binary image. Figure 3(a) shows an example of artificial line patterns significantly concentrating to one point in the 3D space, and Figure 3(b) and (c) show the results of calculating the index for this artificial line pattern. Figure 3(a) consists of an input pattern with 26 short line segments which concentrate to the
center point of the image. The size of the neighborhood region $R(r_1=50\text{ pixels and } r_2=100\text{pixels})$ used in this experiment is shown in Figure 3(a). Figure 3(b) shows the concentration index images in which each voxel has the value of the concentration index. Figure 3(c) shows cross sections of Figure 3(b). The concentration index image resulting from a 3D line pattern with clear concentration point like Figure 3(a) always contains a region of high concentration index at the center of the image. This high index region is surrounded by a lower index region which is surrounded again by a high index region as observed in Figure 3.

3.2. Expected value of the concentration index

It is very important to know the expected value of the concentration index because it will provide information of a good threshold for extracting high concentration index region. To estimate it, the concentration index was calculated for line patterns generated by varying the position and the direction of line elements randomly. The ratio of $r_1$ to $r_2$ ($=301$) in $R$ was varied with $1.0 \times 10^{-5}$, 0.25, 0.5 or 0.75. From this simulation, it is estimated that the expected value of the concentration index is nearly 0.5 in any value of the ratio $r_1/r_2$.

4. Application to practical CT images

In this section, the 3D concentration index is applied to real chest X-ray CT images for quantifying the convergence of blood vessels and bronchi in the images. In the case of the malignant tumors (especially adenocarcinoma) growing in the peripheral lung, the shrink of tissue surrounding tumors causes the phenomenon called “convergence” frequently. This phenomenon is an important criterion to discriminate malignant tumors from benign one.

Twenty-nine practical chest X-ray CT images which were taken by the X-ray helical CT scanner were used in the experiment. The voxel sizes in a slice are 0.31-0.41mm, the reconstruction pitch is 1.0mm, the size of a slice is $512 \times 512$ and the numbers of slices are 60-63. We assume that the positions of tumors are known. An example of the CT image displayed by MIP (Maximum Intensity Projection) is shown in Figure 4(a). The regions of tumors are decided slice by slice for each case, and extracted tumors were approximated as ellipsoids which have the same directions of the principal axes as the coordinate axes.

"The average concentration index" was defined as the average of the concentration indexes inside the ellipsoid of the half size of that approximated the tumor.

Figure 4(b) shows the blood vessels and the bronchi region image which were extracted from the CT image by the method shown in Ref.[7], and Figure 4(c) shows its thinning result by the thinning algorithm using Euclidean distance transform[8]. The concentration index images are shown in Figure 5 with the cross sections including the center of the tumors. Grey values in the image are in proportion to the values of the concentration index. The sizes of $R$ are $r_1=10\text{mm}$ and $r_2=20\text{mm}$. The real size is indicated at the upper-left corner of the concentration index images. As for the data08 (adenocarcinoma) with the intense convergence, the average concentration index is significantly higher than other lung region (Figure 5).

The significance of difference between the distributions of cases with convergence and cases without convergence is statistically examined by Mann-Whitney test. The null hypothesis is "There is no difference between two distributions". The null hypothesis was rejected with the level of significance 0.01. This means that there is a trend which the average concentration index takes significantly a higher value for cases with convergence.

5. Conclusion

In this paper, a local feature called the 3D concentration index for analyzing 3D line patterns was proposed. First, basic properties were examined through experiments using artificial line patterns. Second, the 3D concentration index was applied to quantification of convergence of blood vessels and bronchi in practical X-ray CT images, and the relationship between the average 3D concentration index and the degree of convergence given by medical doctors was confirmed. This means that the 3D concentration index is a useful feature to discriminate benign lung tumors from malignant ones.

The future work includes automated adjustment of parameters for extraction of blood vessels and bronchi, and verification of the effectiveness of the index using a larger number of sample cases.

Acknowledgments

Authors thank colleagues in their laboratory for helpful discussion. Parts of the work were supported by the Grant-in-Aid for Scientific Research, Ministry of Education and the Grant-in-Aid for Cancer Research, Ministry of Health and Welfare.
Figure 4. An example of extraction of blood vessels and bronchi from a chest X-ray CT image: (a) an original CT image with tumor, (b) blood vessels and bronchi extracted from (a), and (c) thinning result of (b).

Figure 5. Example of concentration index images obtained from practical CT images (left: original image, right: concentration index image).

References


