Homology-based image analyzing method to quantify the situation of structures

Kazuaki Nakane[1]

[1]Osaka University, the Graduate School of Medicine, Division of Health Science, Yamadaoka, Suita, Osaka, 565-0871, Japan
Email:k-nakane@sahs.med.osaka-u.ac.jp

Abstract: Computer assisted pathological diagnosis is now an important issue in the shortage of pathologists. Because of the complexity of morphology of cancer tissue, various methods have been proposed to analyze them, we have no effective system yet.

One of the common characteristic of cancer is "uncontrolled cell-division", namely "the lack of contact inhibition of cell growth". Recently, our group focus on this property and proposed a simple mathematical model for the identification of tumor areas within normal tissue. Although we have many false positive and the potential of miss the undifferentiated type of cancer, this system is very effective to detect the ROI (a part of tissue that contains important information for diagnosis). In this paper, we will introduce this system and its numerical results. And we will introduce applications to the image of fracture surface. The fracture surface seem to have no-relation with the cancer tissue. However, from the view point of "connection degree", they can be analyzed the same method.

1, Introduction

Many attempts have been tried to analyze the structure images. With the development of image analysis techniques, we have got many valid results. The pattern recognition and Fourier methods have worked effectively for the images that have geometrically well-equipped structure and periodicity patterns. However, there are many structure images that have no mathematical framework at first glance. Only the skilled technicians can analyze these images. Therefore the results depend on the ability of them. Moreover, in this manner, it is impossible to analyze large amount of images.

The homology is a mathematical concept to quantify the contact degree. Essentially, the structures are constructed by the connection of the elements. By calculating *the Betti number* in a unit area, we have tried to classify the situation of the structures.

In the present study, we propose two examples, one is the cancer tissue the other is the fracture surface. They are very complex and there seems to be no relation between them. The common property of them is "growth of the connection". We can identify the image by utilizing changes in *the Betti numbers.* We tested our method in several images and preliminary results are reported.

2, Application to cancer tissue

In Japan, one person is affected with two and one person will die in three by cancer. Cancer is a serious disease and we need to develop actions to overcome. Pathological diagnosis provide important information in determining the cancer treatment policy. The pathologists are performed the diagnosis by passing the eye to all over the specimen using a microscope. Pathological diagnosis starts usually from detection of morphological deviations of tissues and cells in question from their normal counterparts. If they find malignant area, they measure the several data. Then they decide the diagnosis. They do not know where the malignant areas exist in advance. If they miss the malignant area, it causes serious problem to the patients. They concentrate their work.

The number of diagnostic pathologists, however, is significantly small with respect to the large number of clinical cases in Japan. The pathologists are overloaded in their daily work. Because long-time training is needed for pathologist upbringing, it is difficult to increase the number of pathologists immediately. It has been threatened that if we can keep the quality of pathological diagnosis. To improve this situation, development of computer assisted diagnostic system for a pathologist will be one of the effective solutions. Previously, this kind of systems have been developed based on the pattern matching algorithm. Because of the diversity of the morphology of cancer tissue, we have no effective system to analyze them. Here, we introduce a new algorithm that depend on the homology.

Mathematical tools

The Betti number is an important index to represent the contact degree. The definition of *the Betti number* is in [1] and [2]. It is important that *the Betti number* is one of the invariants, that is to say *the Betti number* is unchangeable by continuous transformation. We treat only two dimensional images, the definition of *the Betti number* is very simple. It is consisting of two numbers. One is *b0* (*the 0-dimensional Betti number*), which is the number of such isolated solid component. The other is *b1* (*the 1-dimensional Betti number*), which is the number of windows in the fenestrated area. That area is created by incomplete fusion of neighboring isolated solid component.

The schematic illustration is shown in Figure 1. When the number of contact points between individual solid components increases, i.e., 7 solid components (*b0*) fuse each other through contact, 2 solid components with fenestration are created. They have 4 windows (*b1*). Namely, *b1* increase and the ratio *b1/b0* significantly change.

Normal cells are usually controlled so as to grow and be reproduced only when a tissue composed of the cells requires new cells. That is, a new cell is generated when the old cell dies or is damaged. However, if the foregoing process of cell growth and cell division becomes out of order, the cells grow and divide, excessively. This causes a change in contact condition

between components in a tissue. This change appears along with neoplastic changes and tumorigenesis, as shown in Figure 1, and the real images of colon tissue is shown in Figure 2.

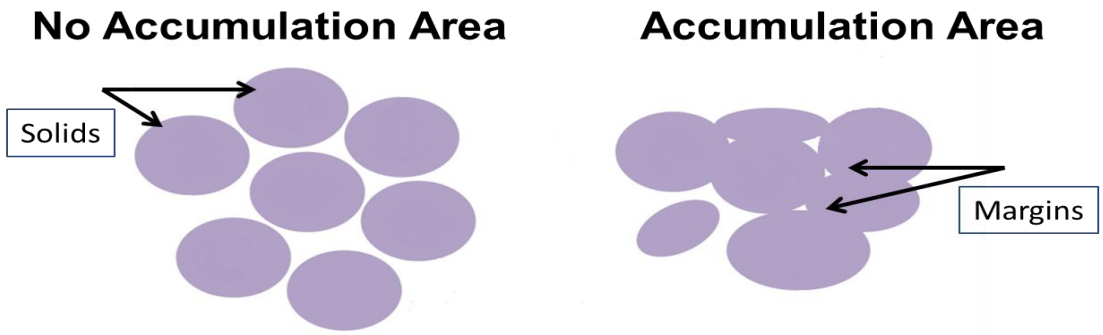
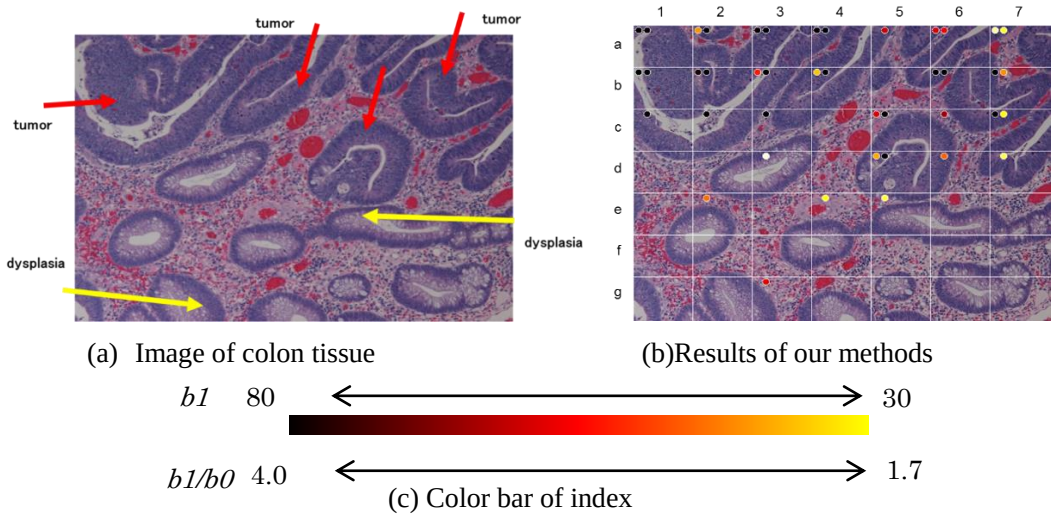


Figure 1: Two indexes are defined, *i.e.*, *b1*[N1] (1st index) and *b1/b0* (2nd index (the ratio)). Left: 1st index=7 and 2nd index = 0.0, Right: 1st index=2 and 2nd index = 2.0[N2].

Feature of our method

We have applied this method to the colon tissue. We divide an image to 7x7 segments and binarize the image by a proper threshold. The binarize threshold is derived from the information of RGB distribution. We calculate *the Betti number* of each segment and put the color dot at the upper left corner depend on the number of indexes (Left *b1*, next *b1/b0*). If the index is low, we put no dots. We show the numerical result on Figure 2. On the lesion, we can see some dot are put.

This idea is firstly introduced by Nakane and Tsuchihashi [3], and Nakane et. al. have confirm the results [4].



(a) Image of colon tissue (b)Results of our methods

(c) Color bar of index

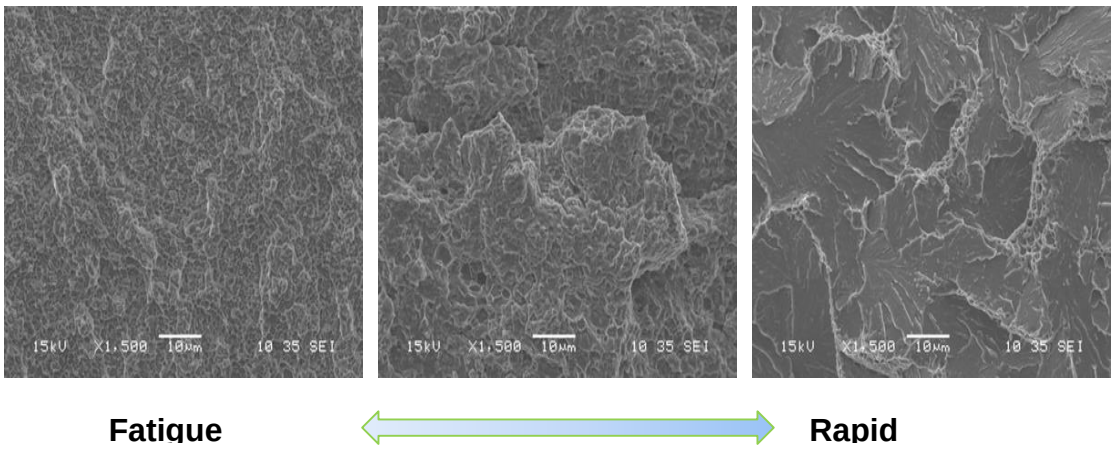
Figure 2: (a) Diagnose of pathologist, tumor is upper half, dysplasia is lower half. (b) The color of the dot indicates the 1st index = *b1* and the next dot indicates the 2nd index = *b1/b0* of each segment. (c) The color indicates the value of indexes.

This system has been used a property of the cancer (loss of contact inhibition), therefore, we have very few false negatives (missed) (the results are shown in [4]). This system works effectively by ordinary computer (Intel i7), since we do not refer the libraries. It takes around 5.0 seconds for one image.

3, Application to the fracture surface

With the development of the modern society, many types of manmade structures have been developed and improved, such as bridges, aircrafts and ships. The accidents caused on the fatigue failure are destroying the important social infrastructures and depriving many lives. To conduct the investigation of the accident, research field called "Fractography" has been developed. They have classified the fracture morphology. The database that they have been accumulated by this research is very important for analyzing the accidents.

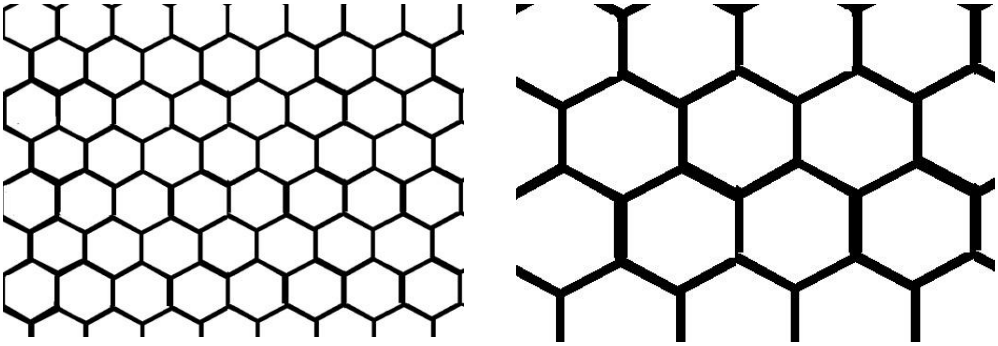
Fracture surface is formed by the stress concentration via the repetition of vibration and the expansion of stress amplitude. Skilled technicians observed these images, they decide fatigue fracture (fracture surface is fine) and rapid break fracture (fracture surface is coarse). We should construct computerized system to get objective decision and to process large amount of images. However, these images are too complex to analyze by using ordinary image analyzing method.



(a) Left (b) Center (c) Right

Figure 3: (a) is the fracture surface without burden. (b) is the fracture surface with a small burden. (c) is the surface that destroyed rapidly.

Figure 4 is a schematic illustration to quantify the fineness of fatigue surface. This idea can be applied to many kind of images.



(a) (b)

Figure 4: Schematic illustration of structures. (a) is a fine structure (*b0=1*, *b1* = 45 and *b1/b0* =45). (b) is a coarse structure (*b0=2*, *b1* = 6 and *b1/b0* =3.0).

We applied this method to the fracture surface of Figure 3. The results are shown in Table 1.

Table 1. The results of our method of Figure 4

	Left	Center	Right
b0	2290	2466	2144
b1	262	164	123
b1/b0	0.114	0.0665	0.0573

Althogh the number of *b0* of three images (a), (b) and (c) do not change so much, the number of *b1* decreas. We can quantify the situation of fatigue surface.

This idea have already applied to the quantify the change of quencing of Fe-C steel and welding steels ([5-11]).

4, Results and conclusion

There are many kind of structures and tissues in the nature. Organized structures, such as the patterns on the skin of creatures, have been studied from the theory and experimental sides. On the other hand, the images we processed here seem to have no mathematical structures. We had no clue to analyze them.

Here, we have applied a topological idea to analyze them. *The Betti number* can be regard as an index of "the connection degree". The structure has size of its own. We estimate the size of the structure (unit area) then we calculate *the Betti number* in each unit area and compare their results. Both cancer tissues and fracture surfaces include random factors. Because we calculate *the Betti numbers* in the predetermined unit area, we can cancel these factors. The index we have used here is topological

invariant, therefore our results is robust to small morphological changes.

Because we calculate *the Betti number* from the binarized images and we do not refer the libraries, the calculation time is very short. Our program works effectively in conventional computers. In near future, we will try other structures.

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