Use of the Structure of Blood Vessel for Detection of Brain Aneurysm and Route Search to Brain Aneurysm

Toshihide MIYAGI, Norihiro ABE
Kyushu Institute of Technology
680-4 Kawazu, Iizuka, Fukuoka 820-8502 Japan
Email: miyagi@sein.mse.kyutech.ac.jp

Yoshimasa Kinoshita
Munakata Suikokai General hospital, Japan

Tatsushi Tokuyasu
Oita National College of Technology,Japan

Hirokazu TAKI
Wakayama University
930 Sakaedani, Wakayama-Shi,
Wakayama 680-8510, Japan

Shoujie He
VuCOMP, USA

Abstract: In this research, we constructed functions that are necessary for the operation simulation system which assists medical students to inhibit brain aneurysm from exploding. The system reported in this paper is "detection of blood vessels", "detection of brain aneurysm" and "route planning to brain aneurysm". Not only the detection method but also the method to reduce the miss detection is realized for the detection of blood vessel.
Finally, the future work will be shown including construction of head model consisting of artery, vein, brain and cranium

Keywords: Medical image processing, Operation simulation, Brain aneurysm, Operation planning, Virtual Reality

1. Introduction

The physician has empirically acquired medical technologies through a medical operation in traditional clinical teaching. However, there is a problem with security and a burden to a patient. The exercise using a pig is difficult to repeat training, and hardship to conduct because of the cost and the protest by a group of protection of animals.
As a new approach for teaching / training in place of the traditional approach, the medical operation simulation system which utilizes virtual reality (VR) attracts attention. The advantage of VR is that it allows trainee to experience various disease state repeatedly and to evaluate know-how quantitatively.
So, this system aims at constructing a medical operation training system for cerebral aneurysm. We will show below the techniques necessary for an operation simulation system.

1. A visual display of an operation object
2. The force feedback using a haptic device
3. A medical operation planning system
4. Implementation of surgical instrument to cut or deform a virtual organ model

Among them, this search tackles 1, 3 to construct a system that detects brain aneurysm from a medical image, and analyzes structures of blood vessels to find a route to brain aneurysm.
This research is conducted based on our experience on both diagnosis of lug cancer or structural analysis of tracheole from CT images [1][2], how to cut a virtual surface model [3] or a virtual voxel model [4] with a scalpel, and simulation of medical manipulation ICSI using a deformable surface model [5].

2. Brain aneurysm

A brain aneurysm generally means a lump or a tumefaction part occurring in a small artery inside the brain. . As a cause of the occurrence, it is considered that there is a weak part on a brain artery wall by nature, and a blood vessel swells out like a lump because blood flow continues meeting with this part for many years. As the result, it occurs at a divergent position between blood vessels.
Treatment for a brain aneurysm is done to prevent an aneurysm from exploding in future. Main treatment is pinching a lump with a clip or inserting coils into a lump.

3. Detection of Blood Vessel

3.1 Detection method of blood vessel

Operation simulation of a brain aneurysm needs to differentiate blood vessel from the other tissues. If a blood vessel is detected as a connected object, then the subsequent process such as the search for the structure of a blood vessel becomes easier. So, a region growing method is applied to a point recognized as a part of a blood vessel in order to detect a consecutive part of a blood vessel.
To an arbitrary pixel given as a starting point, a region growing method merges a neighboring pixel into the same region as the point if the brightness of the pixel is more than or equal to the threshold value.

Consequently, 26 points in the neighborhood of this element have possibility to be a blood vessel, so these points are examined recursively until every point is judged as shown in Fig. 1. The threshold value is adjusted to an adequate one obtained empirically.

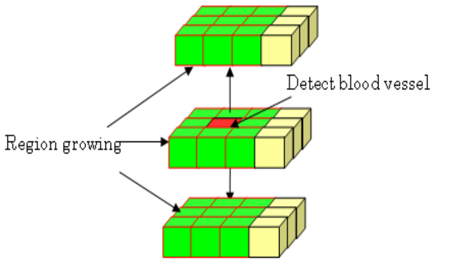

Fig1. The region growing for detect blood vessel

3.2 Deleting method of noise from image

A medical image generally contains noise, so there is some fear that an image element of which brightness value is over the threshold value is misjudged to belong to a blood vessel as shown in Fig. 2 although it doesn't.
As a solution to avoid false detection, this system uses the assumption that the area of a blood vessel is larger than that of falsely detected area.
So, the area of an individual part detected as a blood vessel is calculated, and if it is less than the 1[%] of the maximum area so far recognized as a seaquence of blood vessels , then it is deleted as a noise.

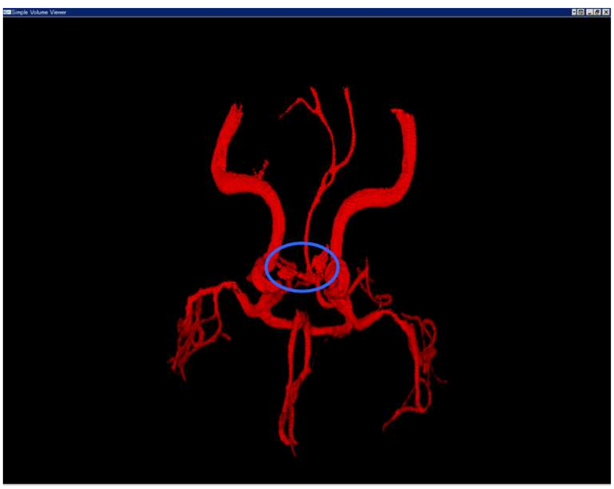

Fig2. False detection of blood vessel

4. Detection of a brain aneurysm

If it is possible to make the location of a brain aneurysm clear in advance before training or diagnosis, it will help not only a trainee confirm a target but also a doctor determine if medical operation is needed or not. .
The appearance of a cerebral aneurysm is a lump shown in Fig. 3. A cerebral aneurysm occurs near the bifurcation between two blood vessels, and the one whose diameter is more than 2[mm] must be detected.
Two methods are used for detecting a cerebral aneurysm; the first one exploits how much a blood vessel is expanded as an index, the second one uses the distance from a bifurcation as an index.
Additionally, we consider the convenience of system when doctor diagnoses using by this system, we construct the change in aspect toward the detected part.

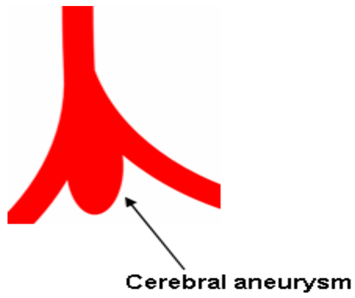

Fig. 3 State of outbreak of cerebral aneurysm

4.1 Detection of using the domain expansion of a blood vessel

Regarding an aneurysm as a part of a sphere, the domain expansion must be repeated two or more times at the point where a blood vessel swelled like a lump as shown in Fig. 4. In this process, it is necessary to judge the bifurcation of a blood vessel while applying the region growing method. For judging bifurcation, connectedness between the expanded areas is calculated, and if there is no connectedness, then there is a bifurcation between them [6]. When a point included in 27-neighborhoods of the current point labeled with a number i on a blood vessel is judged to be on a blood vessel, it is labeled with the number i+1. Only when there is connection between points given the same label in this process, they are determined to be on the same branch, otherwise, a new branch derives from the point; there is a bifurcation. As shown in Fig.5 the elements given a label 6 are not connected each other, so points labeled with 6 are judged as a bifurcation.
Now let the expansion rate be (A-B)/B, where B and A is the area before and after an expansion, respectively. We define a candidate of a cerebral aneurysm to be the portion where expansion whose expansion rate is more than 1.15 occurred successively at least two times.
In Fig. 2, the areas labeled with a number 4 and 5 are detected as a cerebral aneurysm because it suffices the above condition. But, the area of a peripheral blood vessel is so narrow that the increase rate of the area changes greatly. The goal of the system is to detect an aneurysm of which diameter is more than 2mm, then a small area less than the threshold value is not regarded as a candidate. As the spatial resolution in the axial slices is 0.357[mm], and square measure per one pixel is 0.127[mm^2], the number of pixels necessary to detect a cerebral aneurysm is about 25[pixels].

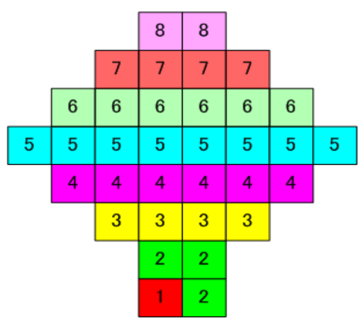

Fig. 4 Detection with the domain expansion

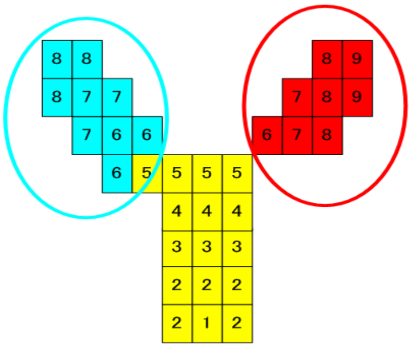

Fig. 5 Detection of the bifurcation

4.2 Detection using the distance from bifurcations

Though the method described in before section is able to detect candidates of a cerebral aneurysm, this method will cause a thick vessel to be regarded as a cerebral aneurysm. But the fact that a brain aneurysm occurs near a bifurcation will find a real brain aneurysm from candidates detected using the method shown in before section.

But, there are two bifurcations at the both end of one branch, so it needs to decide which one should be used to calculate a distance from an aneurysm to the bifurcation. Then, distance between an aneurysm and two bifurcations are calculated and the nearer one is selected as the bifurcation corresponding to an Aneurysm.

Fig. 6 and Fig. 7 will explain how the method is applied. In Fig. 6, L1 and L2 show the distance between a candidate aneurysm and two bifurcations; in this case L1 is shorter than L2, so L1 is regarded as a distance to a detected brain aneurysm. In Fig. 7, the lump area at left side is close to the bifurcation, so it is judged as an aneurysm, and the lump area at right side is so far from a bifurcation that it is considered not to be an aneurysm. This system decides whether candidates are an aneurysm or not based on the condition that the distance from an aneurysm to a bifurcation is shorter than 4[mm] or not.

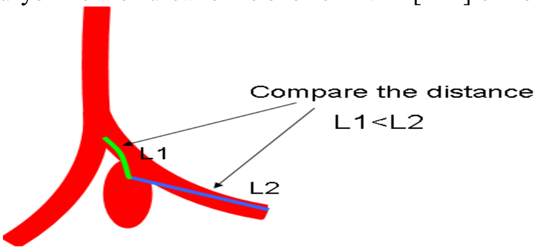

Fig. 6 Compare the distance from bifurcations

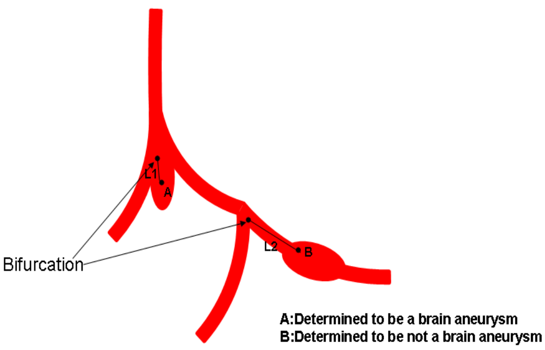

Fig. 7 Detection with the bifurcation distance

4.3 How to display the detected result

As shown above, we proposed the detection method of brain aneurysm. Finally, this system is necessary for a doctor to judge which part is brain aneurysm or not. As there are many cases that the detected part is invisible from the doctor, the function to help the doctor set a view point to make the part visible.

The set method of view point is following.

1. Rotate the image, and draw the image.
2. Capture the drawing result
3. Enumerate the pixel number of yellow(candidate part is shown by yellow)
4. The position that pixel number of yellow is most is decided as a view point

In this method, each axis of coordinate(X and Y) is rotated within the range of -90 degree to 90 degree.

5. Structural analysis of blood vessel for route searching to brain aneurysm

Intravascular operation needs a planning to make a catheter lead to near an aneurysm. Additionally, if the path toward an affected part can be found with a VR system, it is useful not only in an exercise but also in a real operation.

So with use of the result of divergence recognition, a path leading to the affected part is found using A* algorithm.

The process has 3 steps. First, a user decides the aim and start point. Secondly, as an estimate of a cost between the aim point and each bifurcation calculates distance from the aim point to each bifurcation. Finally, it searches the path to the aim point using A* algorithm.

5.1 Route finding based on structure

Connectivity relation between vertex of blood vessel is necessary to search a path using A* algorithm, but it is generated from the recognition result of bifurcation

Let the label of point be a bifurcation point(i) and that of a branch be branch(j).

The one set of information to be stored includes just a label of bifurcation points that are parent and child of one branch and a label of a branch.

We store this information list structure. The making method of this list is shown in following.

Start the following procedure from i=1, j=1, k=2.

(1) Store point (i) as a parent of branch (j).

(2) Perform a bifurcation recognition, and if a bifurcation point point(k) is found, store point(k) to the an child point of branch(j).

(3) If there are n branches of which parent is point (k), then name the one branch selected from them branch(j+1) and store the rest of them in a stack.

(4) in case point(k) is not an end point, then let i=k, k=k+1, j=j+1, and repeat from (1) to (3).

(5) In case point(k) is an end point and a stack is not empty, then pop up a stack, and set i , k, j to the label of a parent of the selected branch, k+1, j+1, respectively, then repeat from (1) to (3).

(6) In else case, end the process.
The method of this is shown in Fig. 8.

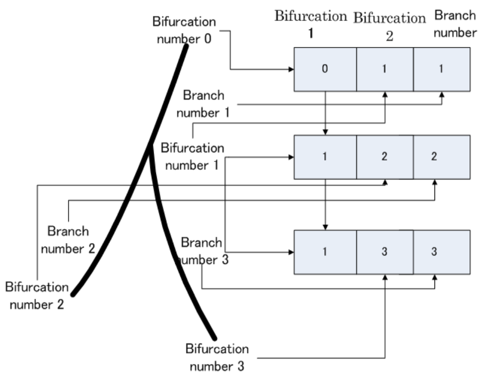

Fig. 8 Acquisition of connection information

6. Execution results

For 4 MRI images provided as samples, detection of brain aneurysm and the route searching to the brain aneurysm using by the structural analysis are tried to verify the validity of the proposed methods. The number of slices is 140, the slice interval is 0.5[mm], and the spatial resolution in the axial slices is 0.357[mm].

6.1 Detection result of blood vessel

It is confirmed that detection of blood vessels is attained as 4 images are successfully processed using the proposed method. For an example, the original medical image and the result of detecting blood vessels are shown in Fig. 9 and Fig. 10, respectively.
The following problems are, however, apparent; there are cases where other than blood vessels are detected as a vessel and cases where a vessel to be detected is not detected as a vessel. This is because there is a problem in setting a threshold value. These problems are removed by adjusting the value, but it is difficult to find the adequate value from a given sample

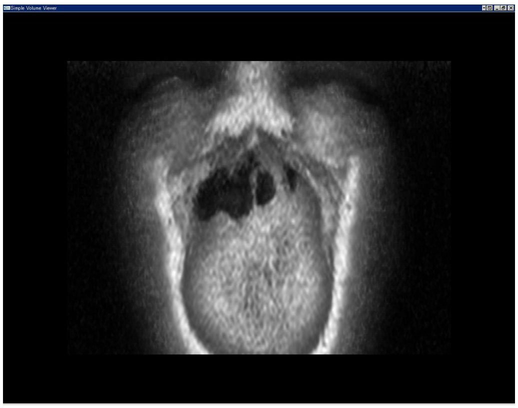
Fig. 9An original image

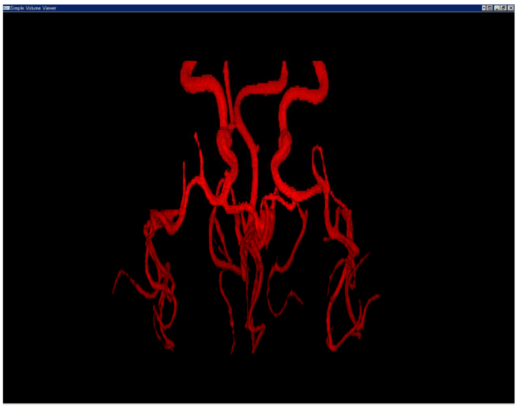
Fig. 10 Detected result of a blood vessel

By removing individual area detected as a vessel if it is less than 1 [%] of the maximally connected blood vessel area, any noise is confirmed to be completely deleted. The results before and after the noise removal are shown in Fig. 11 and Fig. 12, respectively.

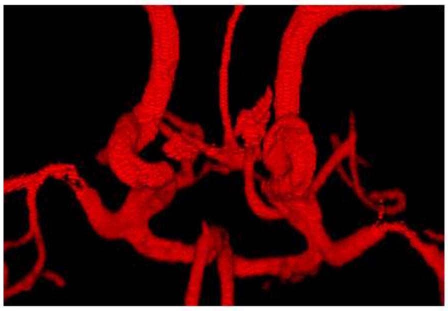
Fig. 11 Before processing

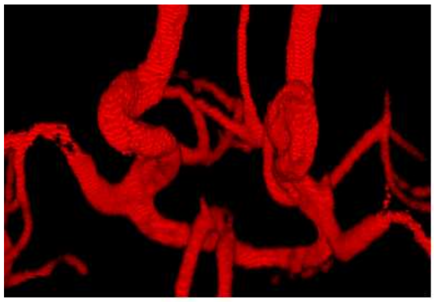
Fig. 12 After processing

6.2 Detection result of brain aneurysm

Fig. 13 shows detection result using by the proposed method, and candidate of brain aneurysm is colored by yellow.
The proposed method is applied to 4 images and the validity of the method is evaluated based on the criteria shown below. The results are divided into two classes as shown in Table 1; the one uses only the domain expansion information and the other uses both the domain expansion information and the distance from bifurcation.
The number of false positives is used as evaluation criteria. A false positive means that an aneurysm is found in the place where none exists in reality.

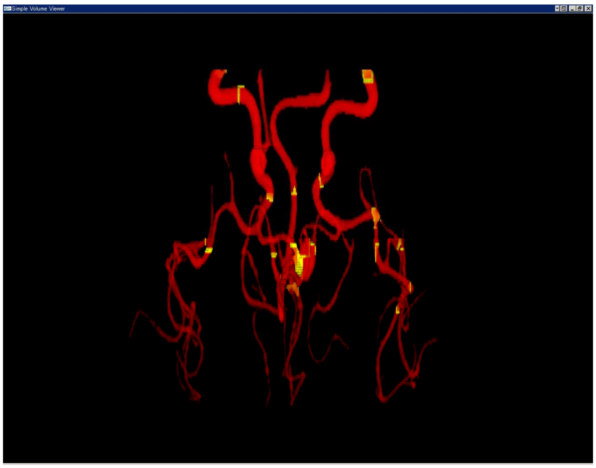

Fig. 13 Detected result of brain aneurysms

Table 1 Result of cerebral aneurysms

	True positive	False Positive [nodules/case]
Not use distance	100%(4/4)	82.25
Use distance	100%(4/4)	36.25

The result of Table 1 shows that proposed method is possible to detect brain aneurysm. And using by the distance from a bifurcation point as an index, the number of false positives decrease about 55.9[%].
But, any other false positives are found in curved portion of vessels. It is because the domain expansion applied to curved portion of a vessel tends to expand the area inside the curve because it is regarded as a part of a vessel.

6.3 Route searching to brain aneurysm using by the structural of blood vessel

Inserting coils into an aneurysm needs navigation leading a catheter to the diseased part. And before the operation, it needs to plan how to move the coil. So, this system constructs the path planning system from arbitrary part to a brain aneurysm using the analysis result of blood vessels.
The brain aneurysm is decided by referring to the detection result of brain aneurysm.
Fig. 14 shows the aim part (brain aneurysm) and start point. And, Fig. 15 shows the route found by using the structural analysis result of blood vessel and by applying A* algorithm to this analysis result.
The result of Fig. 15 shows that route searching succeeds.

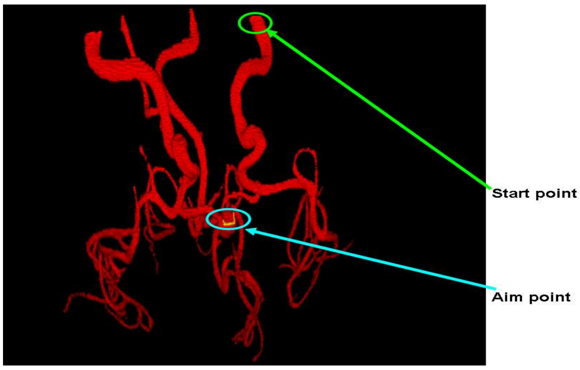

Fig. 14 The aim and start point of search

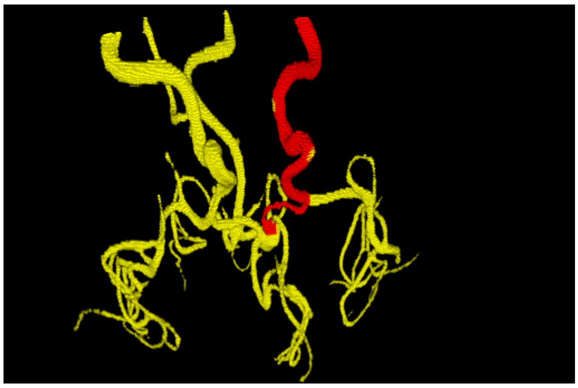

Fig. 15 Route search result to brain aneurysm

7. Conclusion

In this paper, we constructed the function necessary for the development of a medical training system targeting for a brain aneurysm. As a result, we confirmed the following proposed methods are successfully implemented.

1. Detecting a blood vessel
2. Deleting the miss detection result
3. Detecting brain aneurysm and displaying a candidate part
4. Route searching to a brain aneurysm

As a future work, we have to develop the followings,

1. Construction of a model for operation in VR space
2. Construction of surgical instrument in VR space

At present, a head model as shown in Fig. 16 is reconstructed by integrating artery, vein, brain and skull, each of which is detected from CT images. However, artery, vein, brain are soft tissue, voxels constituting them must be transformed into deformable tetrahedron.

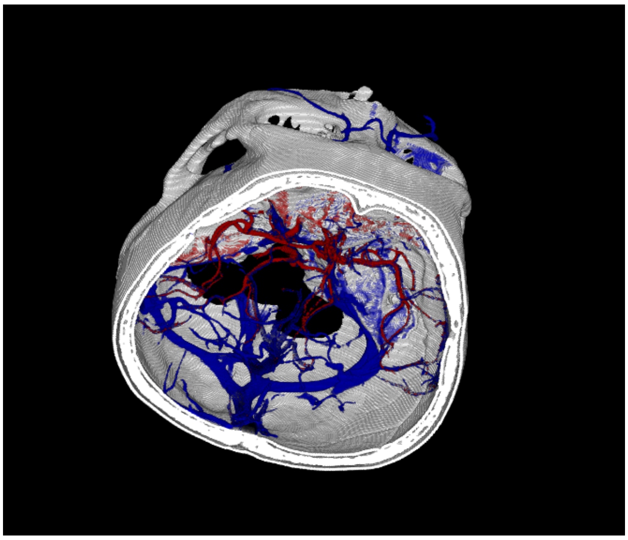

Fig.16 constructed head image

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