Fully-Automatic Labelling of a Selected Aneurysm for Volume Estimation

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Abstract. Nowadays, it is possible to acquire volume representations of the brain with a clear distinction in gray values between tissue and vessel voxels. These volume representations are very suitable for diagnosing an aneurysm. A physician can cure an aneurysm by filling it with coils. We presented a fully-automatic aneurysm labelling method to compute this volume in a previous paper. If an aneurysm is smaller than the "normal" vessels, a bounding box around the aneurysm has to be created. We developed a method to compute such a bounding box with minimal user interaction.

1 Problem and related work

Nowadays, it is possible to acquire volume representations of the brain with a clear distinction in gray values between tissue and vessel voxels [1]. These volume representations are very suitable for diagnosing an aneurysm, a local omnidirectional widening of a vessel (see Fig. 1.1).

A physician can cure an aneurysm by filling it either with coils or glue. Therefore, he/she needs to know the volume of the aneurysm. In [2] we describe a method for fully-automatic labelling of the aneurysm voxels (see Fig. 1.3) after which the volume is computed by counting these voxels.

Our method can be applied only if the aneurysm is wider than the "normal" vessels of the volume (see Section 4.1 of [2]). Nevertheless, if this precondition is violated (see Fig. 1.5), our method can still label the aneurysm if and only if the wide vessel part can be excluded by an axis-aligned volume bounding box around the aneurysm (see Fig. 1.6). The problem is to compute such a bounding box with minimal user interaction.

2 What is new

Creating a bounding box around the aneurysm requires that the user selects one or more 3D points and dimensions so that the resulting bounding box includes the whole aneurysm without any wide vessel part.

To reduce this time-consuming and error-prone interaction and to improve the quality of the resulting bounding box, we developed the first (to the best of our knowledge) semi-automatic method for the creation of a maximal allowed bounding box. The user has to select only one 2D point in a picture of a surface representation of the aneurysm (see Fig. 1.4).

Our starting point is a segmented volume with a 0 for tissue and a 1 for vessel voxels (see [4] and Fig. 1.2), and a surface representation of the vessels (see Fig. 1.4), computed from this segmented volume and the original gray value volume by means of a marching cube algorithm [6].

We use the Manhattan distance transform [5] with regard to the vessel boundaries (we call this distance transform the primary distance transform, abbreviated to PDT, in [2]). The local diameter of a vessel or an aneurysm is given by the maximum PDT of the corresponding cross-section.

The result of our algorithm is a maximal axis-aligned volume bounding box so that "normal"vessel voxels with a PDT greater than or equal to the maximum PDT of the selected aneurysm are excluded (see Fig. 1.6).

3 Method

3.1 Necessary Precondition

Our method gives only valid results if the aneurysm is separated from the connected "normal"vessels by a narrowing:

None of the aneurysm voxels with a PDT equal to the maximum PDT of the aneurysm is connected via a path of face connected voxels, each with a PDT equal to this maximum, to a "normal"vessel voxel with a higher PDT.

This precondition is necessary but not sufficient. In case of an elongated aneurysm, oblique with regard to the co-ordinate system, it is possible that the bounding box of the aneurysm contains a wide vessel part in one of the corners of this box.

The aneurysm voxels with a PDT equal to the maximum PDT of the aneurysm are called the center voxels of the aneurysm.

3.2 The algorithm

After the user has selected a 2D point on the surface of the aneurysm, the following algorithm is used to find the center voxels of the aneurysm (the algorithm will be illustrated using a circle as 2D aneurysm):

1. Scanning the vessel voxels close to the ray defined by the viewpoint and the 3D point corresponding to the selected 2D point, between the front and back side of the indicated vessel part, the algorithm selects the voxel with the maximum PDT as start voxel. If there are more voxels with this maximum, the algorithm selects the voxel closest to the viewpoint. This algorithm finds a start voxel close to the medial axis of the aneurysm.
   Such a ray intersects the circle aneurysm example via a chord. The pixel closest to the center of this chord has the greatest distance to the circle. This pixel is selected as start point.

2. Apply omnidirectional level-climbing to find layers of vessel voxels. A layer consists of voxels which fulfill the following conditions:
   (a) The voxel is face connected to at least one voxel of the previous layer.
   (b) The voxel has a PDT greater than or equal to the maximum PDT of the previous layer.

   The first layer contains the start voxel. Level-climbing stops when a new layer is empty.
   Sometimes, the center voxels do not consist of a single face connected set. So, it is possible that not all center voxels are found by the level-climbing algorithm. Because the Manhattan distance between a center voxel and at least one other center voxel is less than or equal to the maximum PDT of the aneurysm, some of the possibly skipped center voxels can be collected in a new layer using this criterion. If skipped voxels are found, level-climbing continues with this new layer. Else, level-climbing stops.
   In case of the circle aneurysm example omnidirectional level-climbing results in going from the pixel closest to the center of the chord to the pixels closest to the center of the circle.
   Note that all "layer"voxels are close to the medial axis of the aneurysm.
3. Compute the maximum PDT of the "layer"voxels. The center voxels are those "layer"voxels which have a PDT equal to this maximum PDT.
   In case of the circle aneurysm example the pixels closest to the center of the circle are the center voxels.

After the center voxels are found, a maximal allowed bounding box is computed as follows:

1. Create the bounding box for the center voxels.
2. Maximize this bounding box by expanding the six sizes alternately, layer after layer as long as those layers do not contain vessel voxels with a PDT greater than or equal to the maximum PDT of the aneurysm.
   Note that expansion can continue in one direction while the expansion is stopped in another direction.

4 Results

To validate the semi-automatic method for the creation of the bounding box, we used twenty-three aneurysm volumes (four of them 256x256x256, the rest 128x128x128), acquired with the 3D Integris system [3], for which the maximum PDT of the aneurysm is greater than the maximum PDT of the "normal"vessels. The resulting bounding box was equal to the bounding box of all vessel voxels. The fully-automatic labelling method [2] gave exactly the same results with or without bounding box.

To check the utility of the semi-automatic method for the creation of the bounding box, we used nine aneurysm volumes (one of them 256x256x256, the rest 128x128x128) for which the maximum PDT of the aneurysm is less than the maximum PDT of the "normal"vessels (an example is shown in Fig. 1.5). Seven of these volumes resulted in an usable bounding box (an example is shown in Fig. 1.6). Two of these volumes resulted in an erroneous bounding box. Closer examination revealed that in these two cases the necessary condition (see Section 4.1) was violated.

This kind of failures are detected by the algorithm itself because the start voxel is not included in the final aneurysm. In these cases, a new bounding box is created automatically using the position and the PDT of the start voxel and the aneurysm is labelled, still.

5 Discussion

The following conclusions can be drawn from the results, the pictures and the experiences gathered during testing:

1. The semi-automatic method for the creation of a maximal allowed bounding box followed by the fully-automatic aneurysm labelling method gives visually acceptable results, but a clinical validation has yet to be done.
2. In case of an aneurysm with one or more bulges, the user should select a point close to the center of the main part of the aneurysm.
3. This method can be used also in case of multiple aneurysms: only the selected aneurysm is labelled.

Our method may be refined by replacing the axis-aligned volume bounding box by a bounding ellipsoid, aligned with the largest principal axis of the aneurysm. Such a bounding ellipsoid may improve the handling of an elongated oblique aneurysm. In this case, our method for fully-automatic labelling of the aneurysm voxels must be adapted so that it allows for such a bounding ellipsoid.

References

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6 Pictures

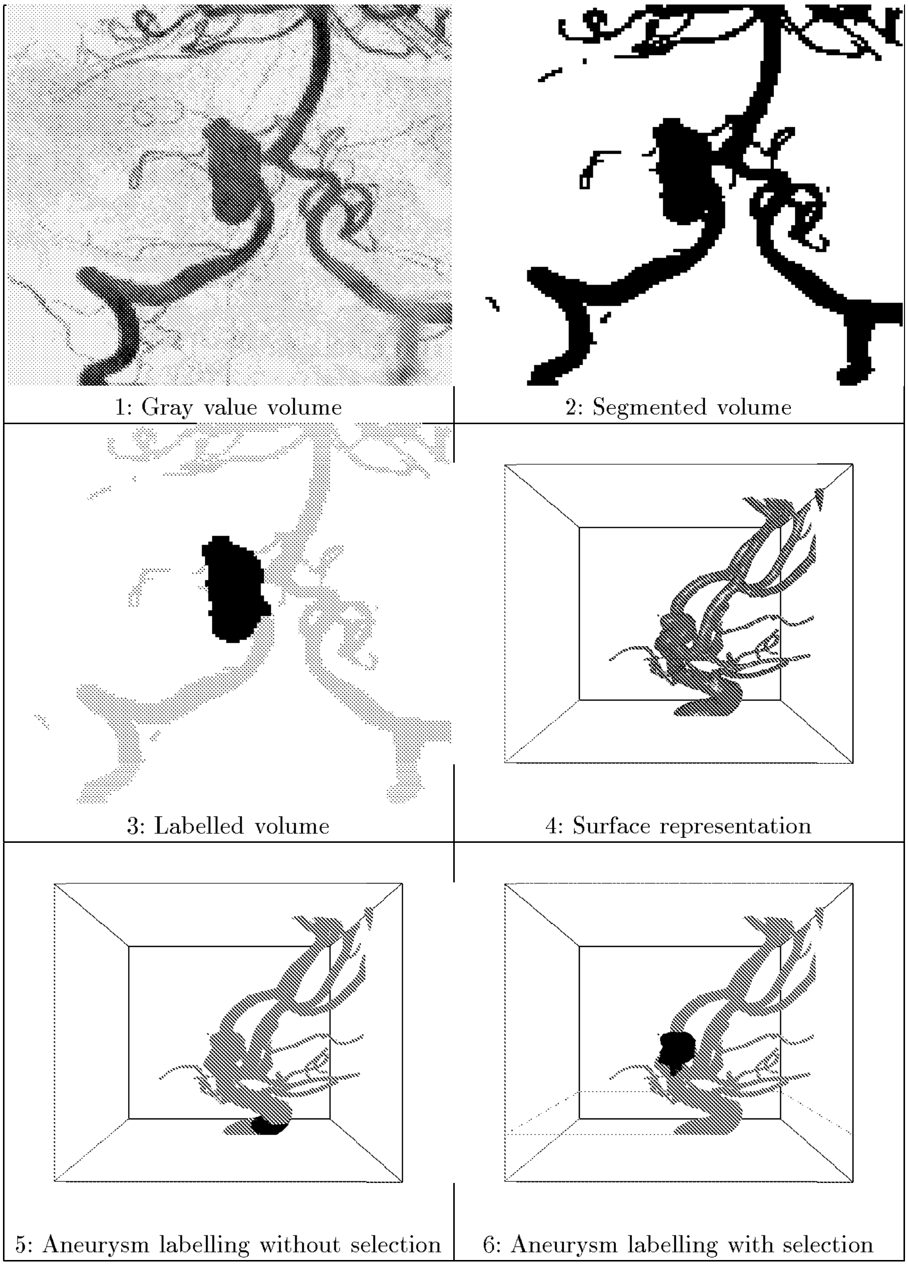

Fig. 1. Aneurysms