Live-Wire Revisited

Zein Salah, Jasmina Orman and Dirk Bartz

WSI/GRIS – VCM, University of Tübingen,
Sand 14, 72076 Tübingen, Germany
Email: salah@gris.uni-tuebingen.de

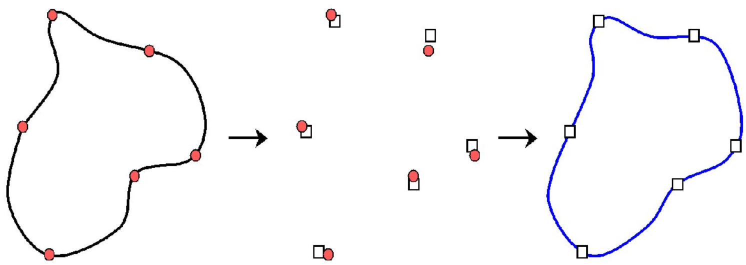
Abstract. The live-wire approach is an interactive, contour-based segmentation technique. Generally, the contour of a targeted object (anatomical structure) is built by interactively selecting control points and finding minimal-cost paths between them. By its very nature, this method is applicable only to 2D images. For the segmentation of 3D datasets (volumes), the interactive generation of live-wire contours has to be applied to each slice of the volume. This process can be quite tedious, due to the sometimes intensive user interaction. In this contribution, we propose adaptive propagation as an alternative to individually processing all image slices or shape-based interpolation of live-wire contours.

1 Introduction and Related Work

In the context of medical image segmentation, and due to object characteristics as well as image quality, a fully-automatic segmentation is in most cases not possible. Moreover, the results of automatic segmentation methods often need further correction. For example, the complex anatomical structure of the mastoid (Figure 3) renders a fully-automatic segmentation as impractical. The segmentation results of the semi-automatic procedure presented in [1] include 10-25% of the slices that require further refinement. However, manual tracing is inaccurate and laboriously unacceptable. Hence, intelligent contour generation methods have been proposed. The *live-wire* [2, 3], also known as *intelligent scissors* [4] is one of the most known methods.

Live-wire is applicable to 2D images. For the segmentation of 3D datasets (volumes), the interactive generation of live-wire contours has to be applied to each slice of the volume. This process can be quite tedious, due to the sometimes intensive user interaction. Several extension of the live-wire approach to 3D images (data volumes) have been addressed in the literature. Principally, the goal is to avoid repeating the interactive generation of contours for all slices. An alternative is to use *Shape-Based Interpolation* [5], where live-wire contours are generated only for some *key* slices. Contours of the missing slices are then interpolated from contours of the key slices. In [6, 7, 8], shape-based interpolation is combined with live-wire. Seed points used for computing live-wire contours at the key slices are interpolated to produce seed points for generating live-wire contours of the missing ones.

Fig. 1. Propagation of Control Points.



In this contribution, we propose a new alternative, which we call adaptive propagation. In our method, control points of the live-wire contours are propagated to the missing slices (not interpolated), without requiring significant user interaction. The core idea is to propagate control points through slices, where the positions of these points are automatically adjusted at each slice. Unlike shape-based interpolation, adaptive propagation does not require a closed contour and is henceforth better suited for rapidly changing objects.

2 Method

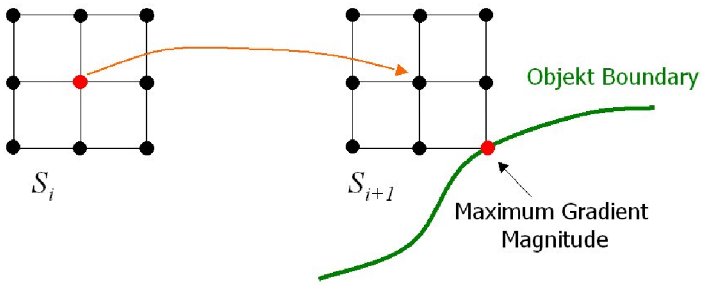
The live-wire approach is slice-based. In the next section, we present a brief overview of the general approach. Adaptive propagation is then described.

2.1 Live-Wire Overview

With live-wire, the extraction of an object boundary is based on the computation of minimal cost paths between vertices of a graph. The two-dimensional image is transferred into a weighted graph, where the vertices of the graph correspond to image pixels and the edges connect neighboring pixels. Edge weights are defined in terms of local cost functions. Usually, pathes are computed using Dijkstra's graph search algorithms and, as a local cost function, the weighted sum of different component functionals that describe edge features [4].

Contour extraction is done by interactively selecting a seed point on the boundary of the targeted object. A second target point is then selected and a minimal cost path from the seed to the target point is computed as described before. Ideally, the path will wrap around the object boundary. If the generated path deviates from the virtual boundary, a new target point is selected nearer to the seed point. Having generated the first path segment, the target point becomes the new seed point and a new path segment is generated similarly. The process is repeated until the whole boundary is outlined. Therewith, the final object contour is composed of multiple minimal-cost path segments.

Fig. 2. Adjausting the position of a propagated control point.



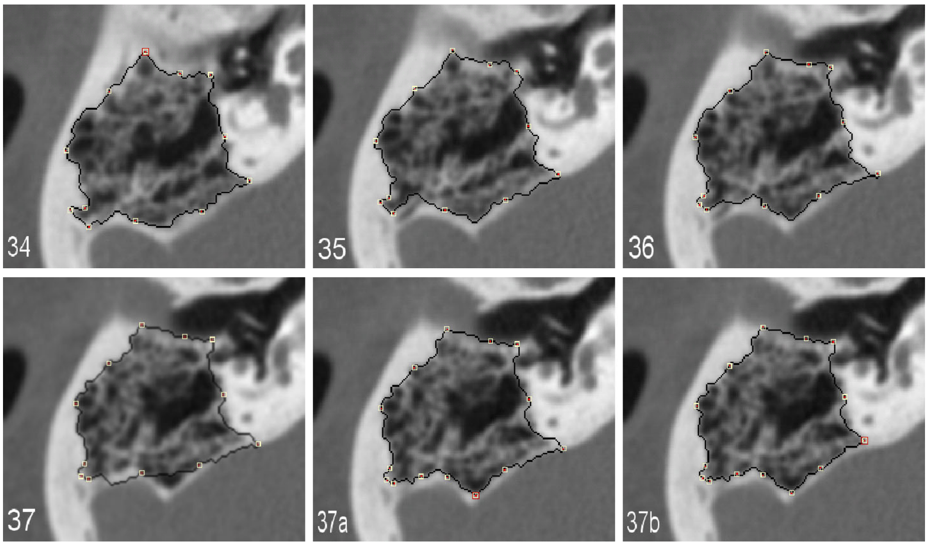
2.2 Adaptive Propagation

The basic idea of adaptive propagation is to reuse information from a current segmented slice to segment the next one. In the first step, we specify the control points of the initial slice using the traditional live-wire approach [4]. The resulted segmentation is defined in terms of a piece-wise contour. Each segment of the contour is computed as a minimal-cost path between two control points. Control points between contour segments can be added interactively to refine the contour. Most of the user time required by the algorithms accounts for this choice of points.

For adaptive propagation, we are propagating the control points of a slice S_i to the next slice S_{i+1} and use them to further compute the new live-wire paths. The idea is illustrated in Figure 1, where the contour on the left is composed of live-wire segments between interactively-selected control points (red circular bullets). These control points are propagated to the next slice. This is motivated by the shape coherence of anatomical structures, i.e., a structure (an organ) does not tend to change in shape rapidly between slices. Hence, the contours of an organ in two successive slices also deviate not much from each other. In this context, propagated points will not necessarily lie exactly on structure contour, but are assumed to be very close to it. In the next step the positions of propagated points are corrected. Adjusted positions are shown by the square bullets in the middle of Figure 1. The idea is simply to move each control point towards the actual contour of the targeted object. Specifically, we search a limited neighborhood of the propagated point for the pixel with the greatest likelihood to lie on the contour, according to the live-wire cost function. As live-wire contours usually resemble edges between an object and its surrounding, we use this heuristic and move the propagated control point to the pixel with the largest gradient magnitude. The concept is illustrated in Figure 2.

After adjusting the positions of all control points, a live-wire path is computed between each two successive points as shown in Figure 1(right). The process is then repeated to the next slice, until all selected slices are processed.

Fig. 3. Propagation example: the contour in slice 34 was generated interactively. The contours in the slices (35, 36, and 37) were generated using propagation, the last two images show refinements of slice 37 performed by inserting new control points.



3 Results

Since the adjustment of control points is heuristic in its very nature, and the shape of an organ might exhibit an unexpected rapid variation between slices, user verification (and may be correction) is still needed. Possibly, new control points must be inserted to refine the contour. However, these situation are relatively rare compared to shape-based interpolation. In our experiments, we tested adaptive propagation with five volume datasets and compared it with shape-based interpolation. On average, 40% of 77 slices from mastoid/ear CT datasets could be processed automatically (with minor corrections) by adaptive propagation, while only less than 20% could be processed automatically by interpolation (also, with minor corrections).

An example is shown in Figure 3, where the live-wire contour of slice 34 was generated interactively. The contours in the subsequent slices (35, 36, and 37) were generated using adaptive propagation. Slice 37 was further refined by inserting new control points (images 37a and 37b).

4 Discussion

In this contribution, we present an extension of the live-wire methods for 3D dataset segmentation, in which the tedious process of generating live-wire contours at every slice of the volume is significantly reduced. In our method, adaptive propagation, the interactive, full creation of contours is performed to only a fraction of the volume slices. Live-wire contours in the missing slices are generated (not interpolated), but without requiring significant user interaction. The idea is to propagate control points through slices, and at each slices, the positions of these points are automatically adjusted. Compared to the interpolation method, adaptive propagation does not rely on closed contours. Furthermore, the generation of new control points depends on the previous slice and not on the first and last of the interpolated slices. Therefore, it adapts better to local variations and is henceforth better suited for rapidly changing objects. Finally, (semi-)automatically generated live-wire contours are usually smoother between slices than manually specified live-wire contours.

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