COMPARISON OF GRADIENT, GRADIENT VECTOR FLOW AND PRESSURE FORCE FOR IMAGE SEGMENTATION USING ACTIVE CONTOURS

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ABSTRACT

When used as the image force for active contours, the gradient has the disadvantage of having a restricted capture range. Two solutions for improving the capture range, gradient vector flow and pressure forces, were compared. Although GVF provides a good capture range, it sometimes leads to boundary delocalisation. As an alternative, pressure forces have shown promising results for histological middle-ear images. The use of open contours was also demonstrated, in addition to the usual closed contours.

Keywords: active contour, discrete dynamic contour, gradient, gradient vector flow, pressure force, snake, middle ear.

INTRODUCTION

Extracting the boundaries of objects in images is one of the most important problems in computer vision and image processing. A wide variety of mathematical and computational approaches has been proposed for solving segmentation problems.

Instead of exploiting only image information as low-level edge-detection techniques do, active contours, or snakes (Kass *et al.*, 1986), also use information about the boundaries as part of an optimisation procedure. Active contours are used extensively for segmentation and a number of alternative approaches have been proposed, such as geometric deformable models (Miller, 1990), discrete dynamic contours (Lobregt & Viergever, 1995) and geometric active contours (Malladi & Sethian, 1996).

The active-contour model involves vertices connected by edge segments with, in general, two associated force terms. The internal force is computed based on the local shape of the contour. The external force (or image force) that drives the active contour to the boundary can be based on any conventional edge-detection technique, *e.g.*, a gradient operator. The internal and external forces may be weighted differently. A damping force may also be used to improve the stability of the deformation process. The interactions of the force terms cause the active contour to evolve from an initial position (*e.g.*, drawn by the user with a mouse) and it converges to the optimal position, *i.e.*, on the structure boundary, where forces balance one another.

The gradient, as an external force, suffers from the drawback of having a weak capture range, and therefore active contours using gradient alone must be initialised close to the boundary. A pressure (or balloon) force (Cohen, 1991) was proposed as an additional term to improve the gradient capture range. The pressure forces are based on the normal vectors at the vertices. The positive or negative sign of the pressure weighting factor determines whether the active contour inflates or deflates.

Xu & Prince (1997) found that pressure forces may overwhelm subjective contours (parts of a boundary with weak or zero contrast). They proposed Gradient Vector Flow (GVF) to improve the capture range of the image force, and found that it could be applied to subjective contours without overwhelming them. GVF involves a vector field derived by solving a vector diffusion equation which diffuses the gradient vectors of a grey-level image (Xu C & Prince JL, 1997). The solution for the GVF vector field involves a combination of Laplacian and gradient terms, and a blending factor (__) is used for governing the trade-off between them.

The goal of this paper is to compare the performance of active contours (in particular, the discrete dynamic contours of Lobregt & Viergever, 1995) using gradient alone, GVF, and gradient with pressure forces for segmentation of histological middle-ear images.

Almost all discussions of segmentation using active contours have involved closed contours. A secondary goal of this paper is to demonstrate the use of open contours.

METHODS

We have developed a semi-automatic computer programme, Oxiana, that implements the discrete dynamic contours of Lobregt & Viergever for both open and closed contours. The programme is written in C. The Gimp Toolkit is used to build the graphical user interface.

Open contours are implemented using the same algorithm as for closed contours except that the starting and ending points are anchored, *i.e.*, are fixed points.

Oxiana also includes additional constraint forces, namely, springs and volcanos (Lobregt & Viergever, 1995). We normally avoid using these constraints in order to minimize the user's interactions.

The examples in this paper involve the malleus and incus, two small bones in the middle ear.

RESULTS

Gradient vs. GVF

Closed active contours using gradient alone gave good results for all structures of interest. The capture range is limited, however, and the initial contour must be located close to the boundary; otherwise the active contours cannot converge to the boundary. Figure 1 shows an initial contour containing seven points, and the active contour after 140 iterations that successfully converged to the boundary.

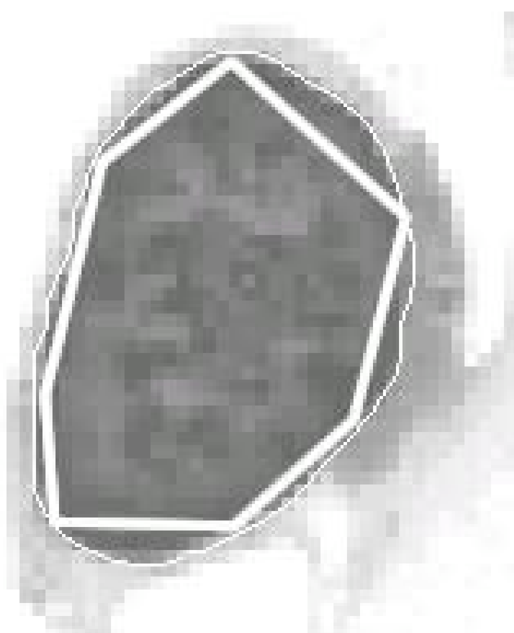

Figure 1: Histological image of malleus. The initial contour (thick line) was defined by the user. The final contour (thin line) was obtained using gradient alone.

The use of GVF reduces the capture-range limitation of the gradient method and the initial contour can be located far from the boundary. Using GVF with ▯ = 0.2, as proposed by Xu & Prince, caused the active contours to overwhelm the boundary for most structures. Figure 2 illustrates an example of overwhelming the boundary using GVF with ▯= 0.2.

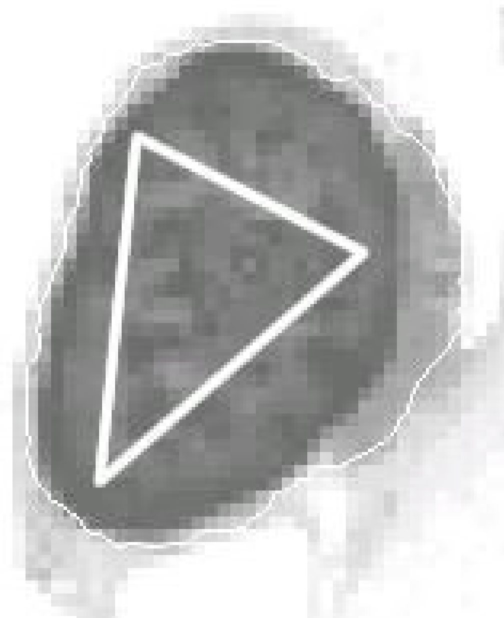

Figure 2: Same structure as in Figure 1, using GVF with ▯= 0.2. The initial and final contours are shown as thick and thin lines, respectively. The GVF force overwhelms the boundary and the final contour is outside the malleus along the right-hand side.

Our results show that the optimal blending factor for GVF depends on the contrast over the boundary, so as the contrast varies from slice to slice the blending factor must be varied. Choosing a smaller blending factor increases the number of iterations since it reduces the GVF force far from the boundary. The proper value for the blending factor was found by trial and error to range from 0.05 to 0.2. For some structures with very low boundary contrast, GVF failed and even very small values for _ were not successful. It is important to note that decreasing _ causes the effect of the Laplacian term to decrease, and when _ is very small, *e.g.*, 0.02, GVF has a behaviour very similar to that of the gradient alone.

Another problem with GVF occurs for close neighbouring structures, *e.g.*, malleus and incus: even with high boundary contrast, GVF may delocalise the boundaries between them. Furthermore, some structures of interest contain small regions of different density and these regions produce false edges. GVF intensifies these false edges, and therefore the starting contour must be initialised far from these edges.

Pressure force

As an alternative approach to improving the capture range of the gradient method, we applied a pressure force. The same initial contours as used for GVF were applied with the pressure force. We found that a pressure weight equal to 0.03 gave good results for all of the structures that we tried. Figure 3 shows the result for a pressure force with a weight of 0.05 for the same initial contour as in Figure 2.

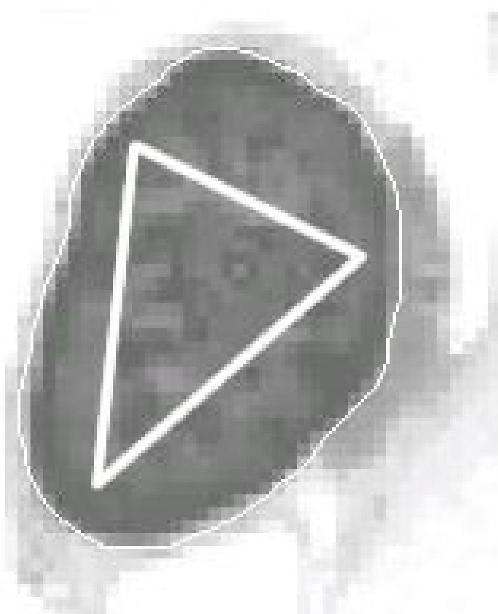

Figure 3: Applying gradient with pressure for the same structure as in Figure 1. The initial contour (thick line) and the final contour (thin line) are shown.

Note that, for the same initial contour, GVF requires a smaller number of iterations than does gradient with pressure. For example, the GVF result in Figure 2 required 30 iterations while the result with gradient and pressure in Figure 3 required 340 iterations.

The advantage of pressure over GVF in the presence of false edges is that increasing the pressure force can overcome the effect of false edges. In contrast, increasing the GVF blending factor will actually intensify the false edges.

With Oxiana, we can turn on and turn off the pressure or GVF at any time. If the active contour moves past the desired boundary because of the pressure or GVF force, then by turning off the pressure or GVF we can apply only the gradient and within a few iterations the active contour will successfully converge to the boundary.

Open contours

Open contours can explicitly represent both the shared boundaries of structures and also very thin structures, such as the eardrum (Van Wijhe, 2000), which are to be modelled as single layers. Figure 4 shows an example of using an open contour to segment the shared boundary between the malleus bone and the neighbouring soft tissue. For this example, gradient with pressure was applied.

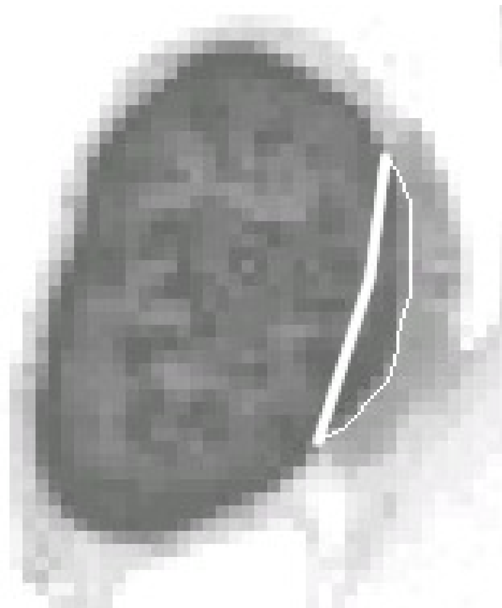

Figure 4: Delineation of the shared boundary between the malleus bone and the neighbouring soft tissue with an open contour. Gradient with pressure (pressure weight = 0.05) was used. The initial contour (thick line) and the final contour (thin line) are shown.

Timing

Note that GVF is computationally much more expensive than the gradient. For instance, for a histology slice (770×500 pixels) computing the gradient of the image took 2 seconds, while the GVF computation took 20 seconds. (Both algorithms were implemented in C and run on a machine with a 1-GHz Intel processor and 1 GB of RAM.)

CONCLUSION

Applying our Oxiana software, active-contour segmentations of middle-ear structures were performed using gradient alone, using GVF and using gradient with pressure. For both closed and open contours, gradient was successful for delineation of all structures if the starting contour was close enough to the desired boundary. As an alternative, GVF was applied to improve the limited capture range of gradient, but it sometimes led to edge delocalisation for boundary regions with low contrast and for boundary regions between nearby structures. In addition, finding a proper blending factor for GVF required trial and error for individual structures. Using a pressure term, however, successfully improved the capture range for gradient, with a single weighting factor for all structures.

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