A New Implicit Method for Surface Segmentation by Minimal Paths: Applications in 3D Medical Images

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Abstract. We introduce a novel implicit approach for single object segmentation in 3D images. The boundary surface of this object is assumed to contain two known curves (the constraining curves), given by an expert. The aim of our method is to find this surface by exploiting as much as possible the information given in the supplied curves. As for active surfaces, we use a cost potential which penalizes image regions of low interest (most likely areas of low gradient or away from the surface to be extracted). In order to avoid local minima, we introduce a new partial differential equation and use its solution for segmentation. We show that the zero level set of this solution contains the constraining curves as well as a set of paths joining them. These paths globally minimize an energy which is defined from the cost potential. Our approach is in fact an elegant, implicit extension to surfaces of the minimal path framework already known for 2D image segmentation. As for this previous approach, and unlike other variational methods, our method is not prone to local minima traps of the energy. We present a fast implementation which has been successfully applied to 3D medical and synthetic images.

Keywords: Image segmentation, Active contours, Minimal Paths, Level Set method, Object Extraction, Stationary Transport Equation.

1 Introduction

Since their introduction by Kass et al. [15], deformable models have been extensively used to find single and multiple objects in 2D and 3D images. The common use of these models consists in introducing an initial object in the image and deforming it until it reaches a desired target. In most applications, the evolution of the object is chosen in order to most rapidly reduce an energy involving the image data, until a steady state is reached. One of the main drawbacks of this approach is that it suffers from local minima ‘traps’. This is the case when the steady state, reached by the active object, does not correspond to the target but to another local minimum of the energy. An immediate consequence of this behavior is that the active object’s initialization is a crucial step, since the final result depends strongly upon it. Since the publication of [15], much work has been done in order to free active models from the problem of local minima.
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Fig. 1. 3D ultrasound volume of a left ventricle: (a) and (b) show the two parallel slices where the user given curves $\Gamma_1$ and $\Gamma_2$ are drawn. (c) shows a slice perpendicular to the curves in order to show their position with respect to the ventricle. Finally (d) shows the surface containing the constraint curves obtained with our approach. In the upper position we have shown the intersection of the zero level set of $\Psi$ with a vertical plane. In the lower position we have traced some minimal paths between the two constraining curves and a 3D representation of the zero level set, the minimal paths are traced on this surface.

A balloon force was early proposed in [8] to make the model more active and to cope with the shrinking problem, but this force assumes a known direction in the evolution. The introduction of region dependent energies [9, 27, 19] and the use of shape priors approaches [26], contributed to create a more robust framework. In order to avoid local minima of the active contours, [10] proposed an approach to find a global minimum of the energy. However their approach cannot be extended to find the global minimum for an active surface in a 3D image.

In this work, we focus on a novel approach for 3D single object segmentation where the resulting surface globally minimizes a given energy. Our aim is to generate a surface that contains a couple of ‘constraining’ curves ($\Gamma_1$ and $\Gamma_2$) and which is also a segmentation of an object. $\Gamma_1$ and $\Gamma_2$ are supposed to be traced by an expert on the surface to be segmented. Our approach is based on implicitly generating a surface that contains the set of paths globally minimizing an image energy and connecting $\Gamma_1$ and $\Gamma_2$. Moreover, the constraining curves are the only input for the initialization of our model. The paths linking $\Gamma_1$ and $\Gamma_2$ are globally minimal with respect to an energy of the form $\int_{\tilde{\Gamma}} \tilde{P}$. If the incremental cost $\tilde{P}$ is chosen to take lower values on the contours of the 3D image, in particular on the surface of the object to be extracted, global minim-

\[\text{Notice that the expert may obtain these curves with a 2D active contour or interactive tool like with the minimal path approach in [13].}\]