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Integrating Feature Direction Information with a Level Set Formulation for Image Segmentation

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Abstract. A feature-dependent variational level set formulation is proposed for image segmentation. Two second order directional derivatives act as the external constraint in the level set evolution, with the directional derivative across the image features direction playing a key role in contour extraction and another only slightly contributes. To overcome the local gradient limit, we integrate the information from the maximal (in magnitude) second-order directional derivative into a common variational framework. It naturally encourages the level set function to deform (up or down) in opposite directions on either side of the image edges, and thus automatically generates object contours. An additional benefit of this proposed model is that it does not require manual initial contours, and our method can capture weak objects in noisy or intensity-inhomogeneous images. Experiments on infrared and medical images demonstrate its advantages.

AMS subject classifications: 65M10, 78A48

Key words: Image segmentation, level set evolution, variational model, image feature, maximal second-order directional derivative.

1. Introduction

In most computer vision applications, image segmentation is a key initial step before performing high-level tasks such as object recognition and tracking [1, 2]. For a given image, the segmentation problem is to find optimally a set of curves that partition the image domain into different regions such that each region is uniform and homogeneous in one or more characteristics (e.g., intensity, colour or texture). However, many images are characterised by intensity inhomogeneity, noise, texture and weak object, etc., which could cause

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errors in the process of image segmentation. Various different purpose methods, including for example the thresholding algorithm [3], wavelet transformation [4], stochastic algorithm [5], graph cut [6] and variational level set models [7-10], have been proposed for these tasks. We focus on the variational level set method, which has the main advantage that it easily incorporates various prior knowledge such as on gradients and second-order directional derivatives, in formulating an energy functional for robust image segmentation.

The level set method introduced by Osher & Sethian [11] is a versatile tool for interface tracing. In image processing and computer vision applications, variational level set models have been studied extensively for image segmentation [7-10]. These variational level set models express object contour extraction as the minimisation of an energy functional, performed using gradient descent that provides a partial differential equation (PDE) for level set evolution. The zero level set (evolution curve) is used to represent the object contours, and the evolution PDE is subject to constraints from both the level set function (LSF) itself and the image data. According to the difference in constraints from the LSF, the energy functional typically includes the internal energy and external energy. The internal energy smooths the level zero curve and the LSF itself, and the external energy assists robust image segmentation.

Existing level set models for image segmentation can roughly be categorised into two classes — viz. region-based models [8, 10, 12-15] and edge-based models [7, 9, 16, 17]. Region-based models approximate the intensity in each region by global or local statistics information, and edge-based models use local edge information to construct external constraints. These models [7-10, 12-17] are amenable to physical insight into the problem of image segmentation, and build up elegant outputs via variational frameworks, especially for medical [13] and infrared images [17].

Edge-based models [7, 9] generally utilise image gradients to construct edge indicators, which are considered external constraints that stop the contours on the boundaries of the desired objects. However, the information contained in a gradient is limited to a point and its immediate neighbours, which makes the level set evolution highly sensitive to the initial contours. On the other hand, the scale value of the edge indicator is always positive, so the edge indicator cannot vanish along the object boundaries such that the curve propagating cannot stop on the object boundaries and continuously moves into weak object boundaries. In fact, an image is intrinsically a matrix that includes a large amount of data such as the intensity, gradient, or directional information and more. The data in oriented domains characterise image features such as the direction of the image edges. Incorporating the directional information into a variational framework benefits the segmentation performance of the models.

Recently, a number of algorithms incorporated image data in oriented domains into a variational framework, and attracted considerable interest [18-25]. In Ref. [18], an optimal edge-integration was designed with regard to the energy functional, which accumulates the inner product between the normal to the edge and the grey level image-gradient along the edge. Paragios *et al*. [19] proposed a bidirectional geometric flow, by integrating the gradient vector flow into the geodesic active contours (GAC) model [7] that improved the segmentation effect and exhibited more freedom with respect to the initial conditions.