Jasjit S. Suri
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Deformable Models II

Theory and Biomaterial Applications

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Deformable Models

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PREFACE

This volume carries the same flavor as Volume 1 in covering the theory, algorithms, and applications of level sets and deformable models in medical image analysis.

Chapter 1 describes a new approach that integrates the T-Surfaces model and isosurface generation methods within a general framework for segmentation and surface reconstruction in 3D medical images.

Chapter 2 is a study of active contour models in medical image analysis. Various issues with respect to implantation are discussed.

Chapter 3 also deals with active contours with a primary focus on the application and performance of different types of deformable models for analyzing microscopic pathology specimens.

Chapter 4 focuses on construction of the speed function of level sets as applied to segmentation of tagged MR images.

Chapter 5 presents a parallel computational method for 3D image segmentation based on solving the Riemannian mean curvature flow of graphs. The method is applied to segmentation of 3D echocardiographic images.

Chapter 6 provides a review of the level set method and shows the usage of shape models for segmentation of objects in 2D and 3D within a level set framework via regional information.

Chapter 7 also deals with basic application of deformable models to image segmentation. Various applications of the method are presented.

Chapter 8 employs geometric deformable models/level sets to extract the topology of the shape of breast tumors. Using this framework, several features of breast tumors are extracted and subsequently used for classification of breast disease.

Chapter 9 examines various theoretical and algorithmic details of active contour models and their use for image segmentation.

Chapter 10 uses deformable models to devise a segmentation approach for ultrasound images for the study of prostate cancer.

Chapter 11 proposes a novel variational formulation for brain MRI segmentation that uses J-divergence (symmetrized Kullback-Leibler divergence) to measure the dissimilarity between local and global regions.

Chapter 12 examines the use of shape transformations for morphometric analysis in the brain. A shape transformation is a spatial map that adapts an individual's brain anatomy to that of another.

Chapter 13 proposes a nonlinear statistical shape model for level set segmentation. Various algorithmic details are provided to show the effectiveness of the approach.

Chapter 14 uses the level sets methods for structural analysis of brain white and gray matter in normal and dyslexic people.

Chapter 15 describes an approach for estimating left- and right-ventricular deformation from tagged cardiac magnetic resonance imaging using volumetric deformable models constructed from nonuniform rational B-splines (NURBS).

Chapter 16 is a generalization of the methods presented in Chapter 14 with an emphasis on autism. The 3D distance map is used as a shape descriptor of the white matter, and a novel nonrigid registration approach is used to quantify changes in the corpus callosum of normal and autistic individuals.

Overall, the thirty-one chapters in the two volumes provide an elegant cross-section of the theory and application of variational and PDE approaches in medical image analysis. Graduate students and researchers at various levels of familiarity with these techniques will find the two volumes very useful for understanding the theory and algorithmic implementations. In addition, the various case studies provided demonstrate the power of these techniques in clinical applications.

The editors of the two volumes once again express their deep appreciation to the staff at Springer who made this project a fruitful experience.

Jasjit Suri and Aly Farag
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CONTENTS

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T-SURFACES FRAMEWORK FOR OFFSET GENERATION AND SEMIAUTOMATIC 3D SEGMENTATION

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This chapter describes a new approach that integrates the T-Surfaces model and isosurface generation methods in a general framework for segmentation and surface reconstruction in 3D medical images. Besides, the T-Surfaces model is applied for offset generation in the context of geometry extraction. T-Surfaces is a parametric deformable model based on a triangulation of the image domain, a discrete surface model, and an image threshold. Two types of isosurface generation methods are considered in this work: continuation and marching. The continuation approach is useful during reparameterization of T-Surfaces, while the latter is suitable to initialize the model closer the boundary. First, the T-Surfaces grid and the threshold are used to define a coarser image resolution. This field is thresholded to obtained a 0–1 function that is processed by a marching method to generate

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polygonal surfaces whose interior may contain the desired objects. If a polygonal surface involves more than one object, the resolution is increased in that specific region, and the marching procedure is applied again. Next, we apply T-Surfaces to improve the result. If the obtained topology remains incorrect, we enable the user to modify the topology by an interactive method based on the T-Surfaces framework. Finally, we discuss the utility of diffusion methods and implicit deformable models for our approach.

1. INTRODUCTION

Deformable Models, which include the popular *snake models* [1] and deformable surfaces [2, 3], are well-known techniques for boundary extraction and tracking in 2D/3D images. Basically, these models can be classified into three categories: parametric, geodesic snakes, and implicit models. The relationships between these categories have been demonstrated in several works [4, 5].

Parametric Deformable Models consist of a curve (or surface) that can dynamically conform to object shapes in response to internal (elastic) and external (image and constraint) forces [6]. In geodesic snakes formulations, the key idea is to construct the evolution of a contour as a geodesic computation. A special metric is proposed (based on the gradient of the image field) to let the state of minimal energy correspond to the desired boundary. This approach allows addressing the parameterization dependence of parametric snake models and can be extended to three dimensions through the theory of minimal surfaces [7, 5]. Implicit models, such as the formulation used in [8], consist of embedding the snake as the zero level set of a higher-dimensional function and to solve the corresponding equation of motion. Such methodologies are best suited for the recovery of objects with unknown topologies.

When considering the three mentioned categories, two aspects are fundamental within the context of the present work: user interaction and topological changes. Parametric models are more suitable for user interaction than the others because they use neither the higher-dimensional formulations of Level Sets nor globally defined features, like the metric in the geodesic approach. However, for most parametric methods the topology of the structures of interest must be known in advance since the mathematical model cannot deal with topological changes without adding extra machinery [9, 10].

Recently, McInerney and Terzopoulos [11, 9, 10] proposed the T-Snakes/T-Surfaces model to add topological capabilities (*splits and merges*) to a parametric model. The resulting method has the power of an implicit approach without requiring a higher-dimensional formulation.

The basic idea is to embed a discrete deformable model within the framework of a simplicial domain decomposition (*triangulation*) of the image domain. In this framework, the reparameterization is based on the projection of the curve/surface over the triangulation and on a *Characteristic Function*, which distinguishes the interior grid nodes of the (closed) curve/surface from the exterior ones. The set

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