Nonlinear Image Labeling for Multivalued Segmentation

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***Abstract*— In this paper, we describe a framework for *multivalued* segmentation and demonstrate that some of the problems affecting common region-based algorithms can be overcome by integrating statistical and topological methods in a nonlinear fashion. We address sensitivity to parameter setting, the difficulty with handling global contextual information, and the dependence of results on analysis order and on initial conditions. We develop our method within a theoretical framework and resort to the definition of image segmentation as an estimation problem. We show that, thanks to an adaptive image scanning mechanism, there is no need of iterations to propagate a global context efficiently. The keyword *multivalued* refers to a result property, which spans over a set of solutions. The advantage is twofold: first, there is no necessity for setting *a priori* input thresholds; secondly, we are able to cope successfully with the problem of uncertainties in the signal model. To this end, we adopt a modified version of fuzzy connectedness, which proves particularly useful to account for densitometric and topological information simultaneously. The algorithm was tested on several synthetic and real images. Peculiarities of the method are assessed both qualitatively and quantitatively.**

I. Introduction

IN RECENT YEARS, three classes of techniques for image processing have been particularly improved; we attempt to integrate them to overcome the usual drawbacks of region-based segmentation methods. Statistical, contextual signal characteristics and *a priori* knowledge are exploited in the Bayesian framework, morphological aspects are taken into account by mathematical morphology (MM) and related methods, and fuzzy techniques handle model uncertainties and represent a useful tool for describing topological features.

The proposed adaptive, nonlinear processing method for multivalue region growing overcomes the drawbacks of dependence on analysis order and on initial conditions, of inability to take into account global information, and of sensitivity to parameters. The segmentation problem is reduced to a domain-independent estimation problem, suitable for application to real images of the "bird's eye view" type.

Our noniterative approach is based on a selective growing mechanism and regards an image as a time-series model made up of sequences of random variables, thus avoiding the time and convergence problems typical for iterative methods. Each sequence is analyzed by a first-order nonlinear recursive operator.

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Accordingly, the method is implemented by performing two main processes—the image scanning or growing process and the actual pixel-labeling process. The former decides on the candidate pixels to be analyzed (on the basis of already labeled pixels) and results in the selection of the best paths starting from a fixed seed point. The latter assigns a label to each candidate pixel, in accordance with neighboring points and with the seed point.

Second-order statistical features are exploited to account for local and global information. To this end, a modified version of fuzzy connectivity, derived from the classical definition by Rosenfeld [1] and called *intensity connectedness*, is introduced. This measure allows one to use topology and intensity information simultaneously.

As a result, the 2-D image-labeling process is reduced to a sequence of 1-D processes, that is, the image is divided into a set of 1-D signals, each corresponding to the best path from a generic pixel to the seed point.

Without setting any parameter and threshold values, we obtain a multivalue segmentation result that compensates for the lack of an objective description of the segmentation. Sets of possible regions and contours of an object, named *isoregions* and *isocontours*, are derived from the labeled image. Among these, the most appropriate may be selected either manually (during a semi-interactive session) or automatically, for instance, by exploiting the domain model contained in a knowledge-based system [2].

To sum up, the main innovative aspects of the paper are as follows:

- multivalue characteristics of segmentation results, obtained independently of parameter and threshold values;
- reduction of image processing to a set of 1-D processes while preserving topological relations;
- integration of the statistical approach with fuzzy techniques able to handle also topological information;
- modified version of fuzzy connectivity to take into account topological and densitometric features at the same time;
- innovative image-scanning mechanism that, being adaptive to the image content, allows a noniterative approach to account for contextual information;
- good quality of results and the robustness and the speed of the method, as proved by the results obtained on real images.

The paper is organized as follows. After citing works on the topics addressed in the paper, a modification to the classical fuzzy connectedness formula is proposed. The two main tasks

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