Applied Soft Computing 44 (2016) 1–29

Contents lists available at ScienceDirect

Applied Soft Computing

journal homepage: www.elsevier.com/locate/asoc

Review Article

A survey on image segmentation using metaheuristic-based deformable models: state of the art and critical analysis

Pablo Mesejo[a,b,c], Óscar Ibáñez[d,*], Óscar Cordón[d], Stefano Cagnoni[a]

[a] Department of Information Engineering, University of Parma, Viale G.P. Usberti 181a, 43124 Parma, Italy
[b] ISIT-UMR 6284 CNRS, Université d'Auvergne, Clermont-Ferrand, France
[c] INRIA, Univ. Grenoble Alpes, LJK, F-38000 Grenoble, France
[d] Department of Computer Science and Artificial Intelligence, University of Granada, C/ Daniel Saucedo Aranda, 18071 Granada, Spain

ARTICLE INFO

Article history:
Received 16 December 2014
Received in revised form 20 July 2015
Accepted 3 March 2016
Available online 10 March 2016

Keywords:
Deformable models
Metaheuristics
Image segmentation
Stochastic optimization
Global continuous optimization

ABSTRACT

Deformable models are segmentation techniques that adapt a curve with the goal of maximizing its overlap with the actual contour of an object of interest within an image. Such a process requires the definition of an optimization framework whose most critical issues include: choosing an optimization method which exhibits robustness with respect to noisy and highly-multimodal search spaces; selecting the optimization and segmentation algorithms' parameters; choosing the representation for encoding prior knowledge on the image domain of interest; and initializing the curve in a location which favors its convergence onto the boundary of the object of interest.

All these problems are extensively discussed within this manuscript, with reference to the family of global stochastic optimization techniques that are generally termed metaheuristics, and are designed to solve complex optimization and machine learning problems. In particular, we present a complete study on the application of metaheuristics to image segmentation based on deformable models. This survey studies, analyzes and contextualizes the most notable and recent works on this topic, proposing an original categorization for these hybrid approaches. It aims to serve as a reference work which proposes some guidelines for choosing and designing the most appropriate combination of deformable models and metaheuristics when facing a given segmentation problem.

After recalling the principles underlying deformable models and metaheuristics, we broadly review the different hybrid approaches employed to solve image segmentation problems, and conclude with a general discussion about methodological and design issues as well as future research and application trends.

Contents

* Corresponding author at: c/. Daniel Saucedo Aranda, s/n 18071 Granada, Spain. Tel.: +34 958244019.
E-mail addresses: pmesejo@ce.unipr.it (P. Mesejo), oscar.ibanez@decsai.ugr.es (Ó. Ibáñez), ocordon@decsai.ugr.es (Ó. Cordón), cagnoni@ce.unipr.it (S. Cagnoni).

http://dx.doi.org/10.1016/j.asoc.2016.03.004
1568-4946/

1. Introduction

Image segmentation is defined as the partitioning of an image into non-overlapping regions that are homogeneous with respect to some visual feature, such as intensity or texture [1]. Segmentation algorithms are involved in virtually all computer vision systems, at least in a pre-processing stage, up to practical applications in which segmentation plays a most central role: they range from medical imaging to object detection, traffic control system and video surveillance, among many others. The importance of developing automated methods to accurately perform segmentation is obvious if one is aware about how tedious, time-consuming, subjective and error-prone manual segmentation can be.

According to the general principle on which the segmentation is based, we can build a taxonomy of the different segmentation algorithms distinguishing the following categories [2–4]: thresholding techniques (based on pixel intensity), edge-based methods (boundary localization), region-based approaches (region detection), and deformable models (shape). This paper is focused on deformable models and, in particular, on the role that stochastic optimization techniques (metaheuristics) play in their application. In fact, the segmentation problems solved by deformable models are intrinsically optimization problems. As a very general description, one can say that deformable models start from some initial boundary shape represented as a curve and iteratively modify it by applying various shrinking/expansion operations. These operations are driven by the goal of minimizing an associated energy function which ideally reaches its optimum when the curve perfectly fits the boundary of the object one wants to segment. Therefore, segmentation is reformulated as the global optimization of a multimodal function.

Besides the main global problem of adjusting the deformable model boundaries according to a cost function, optimization methods are at the core of different critical tasks and can be used to solve many image segmentation sub-problems, such as the selection of the parameters that regulate the algorithm (e.g., the weights of the cost function), the initialization of the curve in a location which favors its convergence onto the boundary of the object of interest, or the parameter configuration of some previous image processing step. Most often, the optimization task is solved by using classical numerical optimization methods such as Levenberg-Marquardt, Gauss-Newton or gradient descent, after relaxing the original problem such that the function being optimized becomes approximately convex [5,6]. In addition to the selection of a proper relaxation strategy, these techniques imply that the function to be optimized is differentiable and continuous. At the same time, there is commonly a relevant probability that such local optimization methods get stuck in local minima. In fact, most local optimization techniques perform effectively when the problem under consideration satisfies the said tight mathematical constraints. However, when the search space is non-continuous, noisy, high-dimensional, non-convex or multimodal, those methods are consistently outperformed by stochastic optimization algorithms [7,8].

Metaheuristics are general-purpose stochastic procedures designed to solve complex optimization problems [9]. They are approximate and usually non-deterministic algorithms that guide a search process over the solution space. Unlike methods designed specifically for particular types of optimization tasks, they are general-purpose algorithms and require no particular knowledge about the problem structure other than the objective function itself, when defined, or a sampling of it (training set) when the optimization process is based only on empirical observations. Metaheuristics are characterized by their robustness and ability to exploit the information they accumulate about an initially unknown search space in order to bias the subsequent search towards useful subspaces. They provide an effective approach to