Computerized Medical Imaging and Graphics 43 (2015) 122–129

Contents lists available at ScienceDirect

Computerized Medical Imaging and Graphics

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

Watershed based intelligent scissors

W. Wieclawek*, E. Pietka

Silesian University of Technology, Akademicka 16, 44-100 Gliwice, Poland

ARTICLE INFO

Article history:
Received 31 July 2014
Received in revised form
26 November 2014
Accepted 9 January 2015

Keywords:
Image segmentation
Intelligent scissors
Live-Wire
Watershed
Edge
Boundary
Corridor

ABSTRACT

Watershed based modification of intelligent scissors has been developed. This approach requires a preprocessing phase with anisotropic diffusion to reduce subtle edges. Then, the watershed transform enhances the corridors. Finally, a roaming procedure, developed in this study, delineates the edge selected by a user. Due to a very restrictive set of pixels, subjected to the analysis, this approach significantly reduces the computational complexity. Moreover, the accuracy of the algorithm performance makes often one click point to be sufficient for one edge delineation. The method has been evaluated on structures as different in shape and appearance as the retina layers in OCT exams, chest and abdomen in CT and knee in MR studies. The accuracy is comparable with the traditional Life-Wire approach, whereas the analysis time decreases due to the reduction of the user interaction and number of pixels processed by the method.

1. Introduction

Segmentation of various structures is very important in medical image processing. There are many ways to detect edges in the image. Some solutions are global and rely on detection of the largest possible number of edges. As examples, spatial edge filters (i.e. Roberts, Prewitt, Sobel), detectors (i.e. Canny, Susan) and transforms (i.e. Fourier, wavelet, watershed) can be given. Some of them are highly sensitive and detect many – also very thin – edges. Therefore, they are low resistant to local noise. Others are more noise resistant but often lose edge continuity and thus do not provide correct edge detection of a desired structure.

Some of the methods for edge detection employ the graph theory. Graph-based segmentation methods are a relatively large group of commonly known approaches [2,21,3,5,1,6,8,25–27]. The LW algorithm is the prototype of the title approach that belongs to the interactive methods [2,21,3,5,1,6,8]. The detection of the edge is based on the graph search procedure. Other solutions [25] use graphs to compute the fuzzy connectedness. Huang et al. [26,27] operate in graph domain to correctly segment breast tumours in ultrasound images.

In our work semi-manual tool with user interaction are employed. The Live-Wire (LW) approach [1–3], called also intelligent scissors belongs to this class of methods. The original version of the algorithm features certain drawbacks including numerical complexity and multiple user interaction. Attempt to reduce these drawbacks results in many variations of this method. A typical version has got a bi-partial character. The first step defines the image cost map, which reflects the edge properties of the image pixel and influences the precision. This cost map is used to describe each vertex of the graph, created during the second stage of the algorithm. The graph size strongly depends on the image size as each image pixel is represented by the graph vertex. Subsequently, the graph searching stage, based on the Dijkstra algorithm [4], is performed. It requires a user interaction based on an edge pixel indication. Because different image objects have irregular edges, the number of marked points is often quite large. Additionally, in medical images of 512×512, this graph searching part is very time consuming. The analysis includes the entire image. In order to reduce the time, homogeneous regions could be excluded from the graph searching procedure. Therefore, many modifications that reduce the number of graph vertices is presented in the literature [5–8].

Farin et al. [5] introduce a new semi-automatic segmentation tool which uses a modified concept of user interaction. The segmentation tool is based on the shortest circular path searched within a corridor that is manually drawn by the user along the object boundary. This solution radically increases the user interaction and additionally limits the segmentation process to the manually selected structure.

Semi-automatic method of the corridor generation is presented in [8]. In this method fuzzy C-means (FCM) algorithm is applied. After clustering the image into classes, only vertices corresponding

* Corresponding author. Tel.: +48 322371128.
E-mail addresses: wojciech.wieclawek@polsl.pl (W. Wieclawek), ewa.pietka@polsl.pl (E. Pietka).

http://dx.doi.org/10.1016/j.compmedimag.2015.01.003
0895-6111/

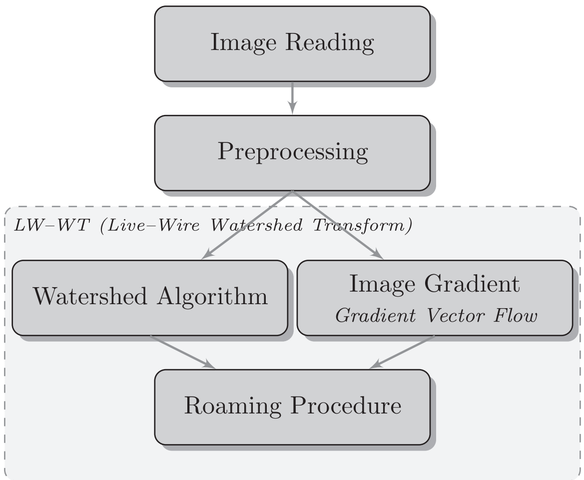

Fig. 1. Workflow.

to pixels whose neighbourhoods are assigned to various classes are subjected to the graph analysis. This action significantly reduces the number of graph vertices (even to several percent of the global number of image pixels), and speeds up graph searching procedure. The class numbers required by the FCM procedure is a drawback of this approach.

The last approach presented in [6,7] reduces the number of pixels by their earlier grouping. Mortensen and Barrett compute the optimal path by over-segmenting the image using tobogganing and then impose a weighted planar graph on top of the resulting region boundaries. The region-based graph is significantly smaller than the pixel-based graph used previously, thus provide a faster graph search and immediate user interaction. Additionally, this approach decreases the number of points marked by the user, particularly for synthetic images (sharp structures with homogeneous background).

In this paper a new approach – Live-Wire with watershed transform (LW-WT) – is discussed. It is a modification of a standard Live-Wire approach [2] where cost map definition has been changed. Moreover, knowing the benefits of corridor solutions [5–7,21,8] these approaches have been developed. Since corridors are obtained either manual [5,21] or by control parameters [8], Watershed transform has been proposed. This transformation draws watersheds lines automatically and is independent on any parameters. The use of corridors reduces the graph size and numerical complexity as well as accelerates the segmentation process. With such defined corridors the number of Seed-Points has been limited. As a corridor based method it has abandoned a cost map analysis usually required in regular intelligent scissors method.

This paper is organized as follows. Section 2 introduces the method discussing all processing phases that include the image preprocessing, followed by the corridors generation and analysis yielding delineation of edges. The results and evaluation of the method are presented in Section 3, followed by a conclusion in Section 4.

2. Method

The proposed application has a bipartite structure (Fig. 1).

The first stage – after `Image Reading` and expected preprocessing – is followed by a watershed based corridor grid extraction (`Watershed Algorithm`) that locates all edges and image gradient analysis that yields the gradient vector flow. Then, a `Roaming Procedure` is performed. It expects a user to indicate the desirable edges. Further processing is fully automatic. On the user request or when no edges are detected, a correction function may be launched.

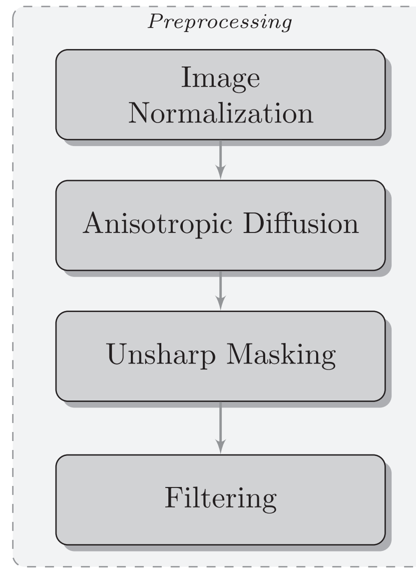

Fig. 2. Preprocessing procedure.

2.1. Preprocessing

The watershed algorithm to be implemented in the following phase requires the local noise suppression. If not reduced it causes over-segmentation or detects edges within homogeneous areas.

In order to preserve the edges an adaptive filtering procedure has been employed (Fig. 2). In our approach anisotropic diffusion is applied [9,10]. It suppresses the noise (impulse and Gaussian) preserving the edges. The filtering kernel parameters are calculated for each image pixel separately.

Then, an edge enhancement procedure (`Unsharp Masking`) is implemented as an arithmetic sum of gradient magnitude and an image subjected previously to an adaptive filtering procedure.

The last stage (`Filtering`) employs a spatial average filtering with Gaussian kernel interspersed, followed by median filtering (with relatively small 7×7 neighbourhood mask) and a mathematical morphology filtering. The latest implements the sequential opening and closing with the smallest, symmetric structural element (defining 8-neighbourhood).

The preprocessed image is subjected to more advanced processing that employs the watershed approach and the gradient vector flow.

2.2. Watershed transform

In order to outline the corridors a watershed transform [11] is implemented. This is a region-based segmentation technique, whose intuitive idea comes from the geography. Watershed algorithm considers a gray level image as a topographic relief, which is flooded by water. One of approaches relies on immersion of the landscape starting from each of a local minimum, called the catchment basin [12]. Then, the water will fill up the local minima. At points where the water coming from different basins would meet, dams will be built. When the water level has reached the highest peak in the landscape, the process stops. As a result, the landscape is partitioned into regions or basins separated by dams, called watershed lines or simply watersheds [13]. Watershed algorithm provides a complete division of the image.