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An agglomerative segmentation framework for non-convex regions within uterine cervix images

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ABSTRACT

The National Cancer Institute has collected a large database of uterine cervix images termed "cervigrams", for cervical cancer screening research. Tissues of interest within the cervigram, in particular the lesions, are of varying sizes and of complexnon-convex shapes. The tissues possess similar color features and their boundaries are not always clear. The main objective of the current work is to provide a segmentation framework for tissues of interest within the cervix, that can cope with these difficulties in an unsupervised manner and with a minimal number of parameters.

The proposed framework transitions from pixels to a set of small coherent regions (superpixels), which are grouped bottom-up into larger, non-convex, perceptually similar regions. The merging process is performed utilizing a new graph-cut criterion termed the normalized-mean cut (NMCut) and an agglomerative clustering framework. Superpixels similarity is computed via a locally scaled similarity measure that combines region and edge information. Segmentation quality is evaluated by measuring the overlap accuracy of the generated segments and tissues that were manually marked by medical experts.

Experiments are conducted on two sets of cervigrams and lead to the following set of observations and conclusions: 1) The generated superpixels provide an accurate decomposition of the different tissues; 2) The local scaling process improves the clustering results; 3) The influence of different graph-cut criterions on the segmentation accuracy is evaluated and the NMCut criterion is shown to provide the best results; 4) A comparison between several modifications to the agglomerative clustering process is conducted. The results are shown to be strongly influenced by the merging procedure; 5) The agglomerative clustering framework is shown to outperform a state-of-the-art spectral clustering algorithm.

1. Introduction

This work is focused on automatic analysis of optical images of the uterine cervix, termed "cervigrams". Cervicography uses visual testing based on color change of cervix tissues when exposed to 3%–5% acetic acid. This helps to detect abnormal cells that turn white (acetowhite) following the application of the acetic acid [11]. In cervicography the uterine cervix is photographed with a special 35 mm camera with a ring flash, used to provide enhanced illumination of the target region. The method can be used for cervical cancer screening and permits archive and study of cervical cancer. Automated cervigram analysis tools such as cervix tissues segmentation, are needed for these tasks. An accurate delineation of the different tissues within the cervix enables the extraction of various features that can be used in successive analysis and indexing steps. The development of an automated cervix tissues segmentation framework is a challenging task, which is handled and discussed in the current work.

The images used in this work were selected from a large database of cervigrams collected by the National Cancer Institute (NCI), National Institute of Health (NIH). This database was collected as part of an ongoing effort for investigating the role of Human Papillomavirus (HPV) in the development of cervical cancer and its intraepithelial precursor lesions in women [22]. NCI in collaboration with the National Library of Medicine (NLM), NIH, is developing a unique Web-based database of the digitized cervix images to study the evolution of lesions related to cervical cancer. The current work is part of an ongoing research that targets the generation of an automated analysis framework for the cervigrams within the NIH archive.

A typical cervigram is presented in Fig. 1(a). The cervix region is the main region of interest within the cervigram. This region can be divided into three tissues of interest, as defined by NCI experts for the automatic analysis task: The squamous epithelium (SE), which is smooth and pink; the columnar epithelium (CE) that appears red and irregular; and the acetowhite (AW) region which is a transient, white-appearing epithelium following the application of acetic acid. The separation between the AW and the SE tissues presents an extremely difficult image segmentation task. The AW tissue can be identified by its color, which is lighter than the color of the surrounding SE tissue

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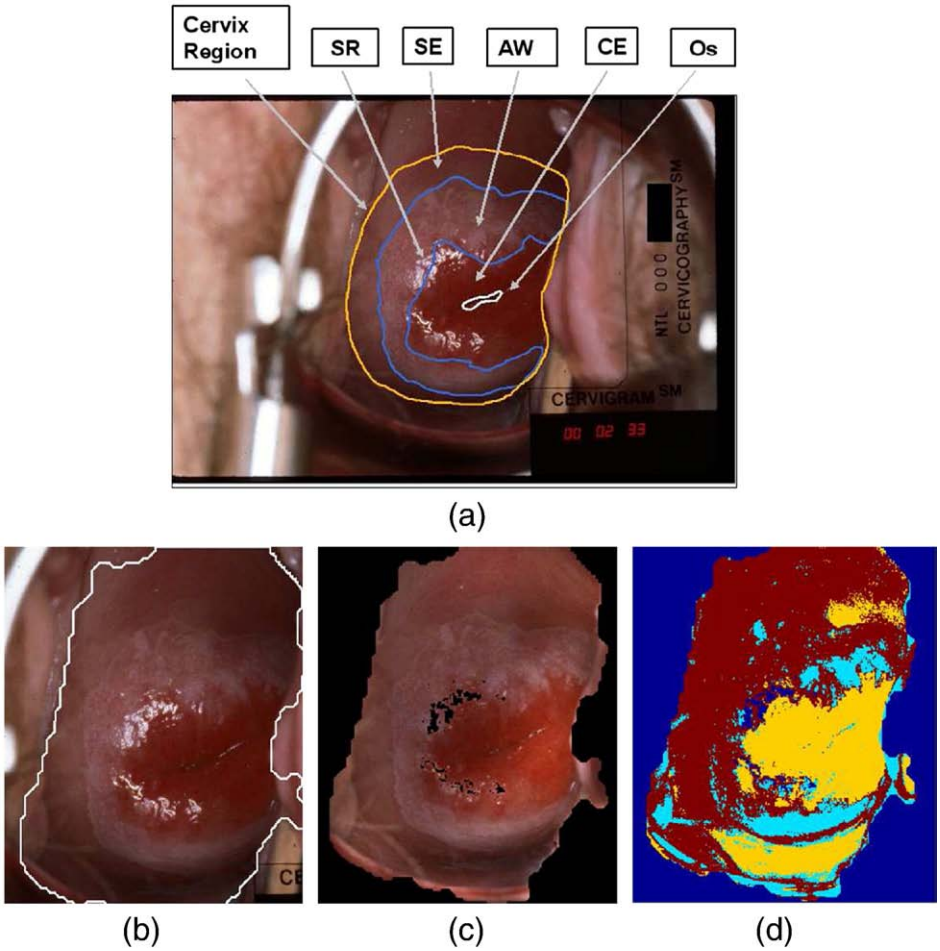

Fig. 1. (a) A typical cervigram: marked are the cervix region, the columnar epithelium (CE), the squamous epithelium (SE), the acetowhite (AW), the entrance to the endocervical canal (Os) and the specular reflection artifacts (SR). (b) Automatically detected cervix boundary imposed on original image; (c) A preprocessed cervigram. SR pixels and regions outside the automatically detected cervix boundary are masked out (marked in black). (d) Color based segmentation results. AW tissue is colored light-blue, CE tissue is colored yellow, SE tissue is colored red, SR and non-cervix regions are colored dark-blue.

and by its boundary, but earlier studies have shown that a large overlap exists between the color distributions of these two tissues [5]. The boundary itself may vary in quality and is not always clearly visible. The AW lesions are of varying shape, size, and can be located in different places within the cervix region. Thus no shape constraints can be imposed to aid the segmentation task and the addition of position constraints is not simple. Specular reflection (SR) artifacts, generated during the image acquisition process, can be detected on the surface of the cervix. These artifacts provide misleading tissue information and interfere with the automatic segmentation.

Initial studies can be found on the analysis of individual cervigram images, or the higher-resolution colposcopic images. Part of these studies are semi-automated, requiring the user to mark regions of interest on various cervix tissues [3,12,20]. Features such as color [20], texture [12], and shape [3] are then extracted and used for classification of the manually extracted regions. Additional works address the task of

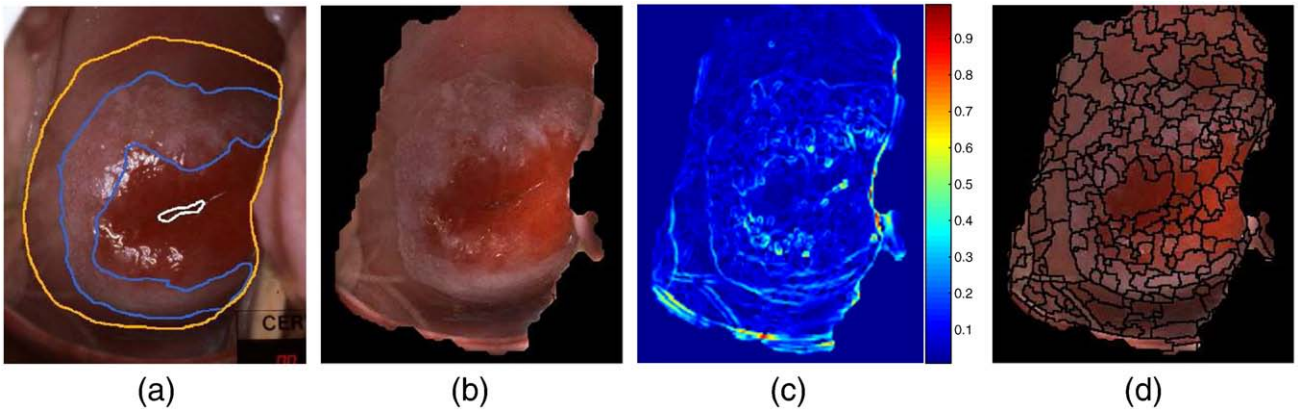

Fig. 2. Superpixels generation process: (a) Original image with manual markings of the expert imposed. Cervix region outlined in yellow, AW region outlined in blue; (b) Enhanced original image, regions outside the automatically detected cervix boundary are masked out (colored black), SR pixels are filled in; (c) Color gradients with local minima imposed; (d) Superpixels boundaries imposed on original image (in black).