Cervical Cancerous Region Detection Using Spectral Matting Technique: A Pilot Study on Color Space

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ABSTRACT Cancerous region detection and identification on medical images is an important technique used in computer assisted diagnosis system to analyze subjects. We have extended previously proposed spectral matting method for natural image to cancer detection for cervical images. Furthermore, we have transformed cervical images to 13 of the most commonly used color spaces—RGB, CMY, CIE-XYZ, CIE-xyY, LAB, LCH, LUV, U'V'L, NTSC, HSI, HSV and YCBCR. Spectral matting results of 13 color models and their pseudo-color images have been presented. ROC curves are employed to make the comparison among them. According to the obtained results, the most appropriate model is CIE-XYZ model to detect cancer area for cervical images.

KEYWORDS Cervical Cancer; Colposcopy; Acetowhite Epithelium; Computer Assisted Diagnosis System (CAD); Spectral Matting; Color Spaces

1 Introduction

Cervical cancer is the second most common malignancy in women worldwide, and it remains a leading cause of cancer-related death for women in developing countries. The incidence of invasive cervical cancer continues to rise in many developing countries[1]. If it is detected early, the probability of cure is very high. After Pap smear test, colposcopy is the most used technique to diagnose this disease because it has a higher sensitivity and specificity[2]. Computer Assisted Diagnosis (CAD) system has attracted significant attention and investment of time and efforts from both academic researchers and industrial developers. In efforts to improve the efficiency and veracity of diagnosis and treatment, image processing techniques are being developed and applied for 1) detection, recognition and analysis of cancer, 2) evaluation of the effectiveness of cancer treatment, and 3) prediction of the risk of cancer development[3]. The advent of digital medical image has lead to an increasingly important and evolving role for image processing and CAD system. A CAD system of uterine cervical images could identify and analyze diagnostic features from cervical images, and derive a clinical diagnosis.

Materials. 53 women with previously detected cytologic abnormalities underwent colposcopy and electrosurgical loop excision procedures in Peru and the United States. Rapid sequence stereoscopic digital cervical images were acquired throughout the colposcopic examination and after excision. Later, a colposcopist annotated a 60 second post acetic acid application image from each subject using a computer drawing program.

Cervical neoplasias exhibit certain morphologic features that can be identified during a colposcopic examination[4]. These features include distinct epithelial and vascular abnormalities. The surrounding normal squamous, metaplastic and columnar epithelium contrast with the abnormal areas. Acetowhite epithelium is one of the major colposcopic signs observed in cervical neoplasia. Although not uniquely abnormal, virtually all cervical neoplasias display a variably transient and opaque white color following the application of 5% acetic acid. Consequently, colposcopic indices consider acetowhite epithelium to help predict the cervical lesions[5].

Levin et al have presented a natural image matting—spectral matting[6]. They extended spectral segmentation from hard segments to soft matting components. Based on these components, they also have described a more direct user interactive mode: the user is presented with the precomputed matting components and may simply label some of them as ground or foreground. This new mode may provide the user with a simple intuitive preview of optional outputs, and thus enables the user to directly control the outcome in the fractional parts of the matte as well. In our work, we take this user interactive mode to give supervision.

Due to light reflection, various amount of illumination and wide inter- and intra-patient variation, cancer area extraction depicted by colposcopic image is much more challenging than natural image matting. In this study, we have found spectral matting based on RGB color space has limitation in some colposcopic images, in which area of acetowhite epithelium is small and healthy region seems like acetowhite epithelium due to light reflection.
The motivation of our study is that compare the behavior of different color spaces extracting acetowhite epithelium in colposcopic image and find the best one. We carry out study among 13 different color space models and do the comparison in pixel level with annotation provided by a colposcopist. These color spaces are RGB, CMY, CIE-XYZ, CIE-xyY, LAB, LCH, LUV, UVL, U’V’L, NTSC, HSI, HSV and YCBCR. Sensitivity and specificity were calculated using annotations provided by a colposcopist as the criterion standard. In spectral matting algorithm, alpha of pixels in matte is between 0 and 1, thus whether a pixel in matte belongs to cancer area must be determined by threshold of alpha. So we have given Receive Operating Characteristic (ROC) curve of 13 color space and have chosen the winner.

We describe spectral matting algorithm in section II and give color space overview in section III. Detection results of 13 color spaces and their pseudo-color images are given in section IV. ROC curve of cancer area extraction in 13 color spaces are given in section V.

2 Spectral Matting

Digital matting assumed that the color of ith pixel in input image I is a composite of a foreground color Fi and a background color Bi,

\[ I_i = \alpha_i F_i + (1 - \alpha_i) B_i \]  

(1)

Where \( \alpha_i \) is pixel’s foreground opacity. Spectral matting generalizes the compositing equation (1):

\[ I_i = \sum_{k=1}^{K} \alpha_i^k F_i^k \]  

(2)

The K vectors \( \alpha_i \) are the matting components of the image, which specify the fractional contribution of each layer to the final color observed at each pixel. The matting components are serve as building blocks for construction of complete foreground mattes.

If the colors of the background and the foreground within a local image window w form two different lines in RGB space, then the \( \alpha \) values within w may be expressed:

\[ \forall i \in w \quad \alpha_i = a_i^B f_i^R + a_i^G f_i^G + a_i^B f_i^B + b \]  

(3)

The matte extraction problem is the one which finds the alpha matte that minimizes the deviation from the linear model (3) over all image windows \( w_q \):

\[ J(\alpha_i, a, b) = \sum_{q \in w_q} (a_i - a_i^q)^2 + (a_i - a_i^q)^2 + (a_i - a_i^q)^2 + b_i^2 + \epsilon \alpha_i^2 \]  

(4)

where \( \epsilon \alpha_i^2 \) is a regularization term on a, a,b may be eliminated from equation (4),yielding a quadratic cost in \( \alpha \) alone,

\[ J(\alpha) = a^T L a \]  

(5)

Here \( L \) is the matting Laplacian . \( L(i,j) \) is defined as:

\[ \sum_{q \in w_q} (\delta_{ij} - (1 + \mu)(\delta_{ij} - \mu) J(i,j)) \]  

(6)

Here \( \delta_{ij} \) is the Kronecker delta, \( \mu_q \) is the 3×1 mean color vector in the window \( w_q \) around pixel \( q \), \( \sum_q \) is the 3×3 covariance matrix in the same window\( w_q \) is the number of pixels in the window, and \( I_1 \) is the 3×3 identity matrix.

Levin et al. states the conditions on local color distribution in each layer, under which \( L \alpha^k = 0 \). That is if the matting components of an image satisfy the condition, they may be expressed as a linear combination of the zero eigenvectors of \( L \). In most real images, the conditions don’t hold exactly. Yet they have empirically observed that the matting components of real images are usually spanned quite well by the smallest eigenvectors of the matting Laplacian. Hence, recovering the matting components of the image is equivalent to finding a linear transformation of the eigenvectors. Let \( E = \{e^1, \ldots, e^K \} \) be the \( N \times K \) matrix of eigenvectors. Our goal is to find a set of \( K \) linear combination vectors \( y_k \) that minimize

\[ \sum_{k} \alpha_k^T E^2 \alpha_k \]  

Subject to \( \sum_k \alpha_k^T = 1 \)

If \( 0 < \gamma < 1 \) is used, then \( \alpha_k^T E^2 \alpha_k \) is a robust score measuring the sparsity of a matting component.

Once matting components extracted from the matting Laplacian, we can recover the a complete by specifying which of the components belong to the foreground. Let \( b \) denote a \( K \)-dimensional binary vector indicating the foreground components. The complete foreground matte is then obtained by simply adding the foreground components together:

\[ \alpha = \sum_k h^k \alpha^k \]  

(8)

If the smallest eigenvalues aren’t exactly zero, we can also measure the quality of the resulting \( \alpha \) matte as \( a^T L a \).

In unsupervised process, we just search for a grouping with the best matting cost, as defined by eq.(5). In order to avoid biasing toward mattes which assign non constant value only to a small subset of the image pixels, one should explicitly keep the size of each group above a certain threshold. In user-guided process, according to user’s foreground /background constrains, it’s usually rule out trivial solutions.

3 Experiment

Women 22 to 50 years old with previously detected abnormal cervical cytologic abnormalities, a
concordant colposcopic diagnosis and scheduled for an electrosurgical loop excision procedure were asked to enroll in the trial. All subjects read and signed an institutional review board-approved informed consent document. Subject confidentiality was protected and no identifying subject information was recorded for the study. Exclusion criteria included cervical hemorrhage, pregnancy, and unwillingness to participate. Image data from fifty three subjects were used in acetowhite epithelium extraction using spectral matting. The subjects were selected from the larger data set based on 1) the presence of an image acquired at 60 seconds post application of 5% acetic acid, 2) an acceptable image – properly focused and of sufficient illumination, and 3) having a colposcopic image that had been manually annotated.

![Fig.1. ROC curves of 13 color models using spectral matting to obtain acetowhite epithelium extraction. Sensitivity and (1-specificity) is x and y axes respectively. Points in ROC curves refer as thresholds of grayscale value and there are 255 points.](image1)

![Fig.2. Detailed graph of Fig.1. Range of x axis is 0-0.1, range of y axis is 0-0.5.](image2)

![Fig.3. Detailed graph of Fig 1. Range of x axis is 0.1-0.5, range of y axis is 0.5-0.975.](image3)

![Fig.4. Detailed graph of Fig1. Range of x axis is 0.5-0.7, range of y axis is 0.975-1.0. Short curve framed in red is ROC curve of LCH model.](image4)
In matte, the grayscale value of every pixel corresponds to alpha value of it. Alpha value refers to the degree that the foreground object contributes to the pixel. Thus high grayscale value denotes that the pixel contains high percentage of foreground object. Whether the pixel belongs to acetowhite epithelium depends on the value of the grayscale or alpha. We have respectively set 255 grayscale values as thresholds to split acetowhite epithelium and non-acetowhite epithelium in matte and analyzed them. Sensitivity and specificity of detection were calculated for the acetowhite epithelium using the colposcopist’s annotations as the criterion standard. The true positive and true negative results were computed based on pixel to pixel match (number of overlapping pixels) between spectral matting thresholding results and colposcopic annotations, the criterion standard. Therefore, sensitivity = area of true positives/(area of true positives + area of false negatives) and specificity = area of true negatives/(area of true negatives + area of false positives). Fig. 1 is ROC curves of 13 color model using spectral matting to obtain acetowhite epithelium extraction. Sensitivity and (1-specificity) is x and y axes respectively. Points in ROC curves refer as thresholds of grayscale value and there are 255 points. In Fig.1, we can see the best color model for detection is XYZ model.

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References


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