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Original Article

Detection of Specular Reflection and Segmentation of Cervix Region in Uterine Cervix Images for Cervical Cancer Screening

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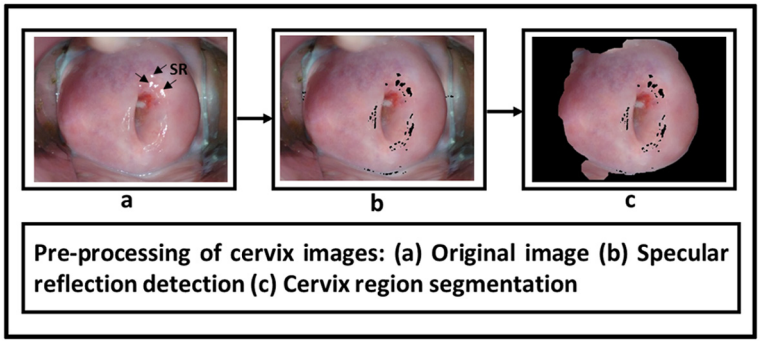
Highlights

- A robust specularity detection algorithm for digital cervix images is proposed.
- Cervix region segmentation using curvilinear structure enhancement is proposed.
- Effectiveness of the algorithm is demonstrated through experimental results.
- Compared the proposed method with the state of the art algorithms.

Graphical abstract



Abstract

Background: Visual Inspection with acetic acid is a screening method for detecting cervical cancer in resource poor settings. Pre-cancerous and cancerous regions turn white on combining with acetic acid. They are called acetowhite regions and can be considered as the indicators of abnormality. Specular reflections, which are bright white regions, interfere with the detection of acetowhite regions and hence need to be eliminated. The irrelevant regions in the cervix images such as medical instruments, vaginal walls etc., need to be eliminated for better processing efficiency.

Methods: In this paper, we propose an algorithm for specular reflection detection using a standard deviation filter and cervix region segmentation using curvilinear structure enhancement. The specular reflection detection algorithm was tested on 151 cervix images. An expert compared the performance of this algorithm with manual evaluation. The cervix border detection algorithm was also tested on the same cervix image dataset.

Results: ROI detection was found to have a sensitivity of 96.75% and a Dice index of 91.72%.

Conclusions: The comparison of proposed method with state of the art algorithms demonstrated that the proposed method is more robust, sensitive and accurate in terms of overlapping metrics.

Keywords: Cervical cancer screening; Specular reflection; Glare removal; Cervix region segmentation; Visual inspection with acetic acid

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1. Introduction

Cervical cancer starts in the cervix and is mostly caused by sexually-acquired infection with Human Papilloma Virus (HPV). It covers 12% of all cancers and is the second most common cause of death among women worldwide [1]. It takes several years for the epithelial changes to progress from pre-cancerous stages to invasive cancer. Therefore, there is adequate time for screening, detection and management of the pre-cancerous stages. The screening methods such as cytology, visual examination, HPV-DNA are used for early detection of the cervical cancer. Pap smear (cytology) is considered as gold standard for cervical cancer screening. However, the requirement for well-established laboratory infrastructure has limited its suitability for resource poor regions. Visual inspection with acetic acid (VIA) is used as a low cost alternative to Pap test [2–4]. In this test, 3–5% acetic acid is applied to cervix and is left for one minute. Pre-cancerous lesions turn white on combining with acetic acid. They are called acetowhite regions and are important diagnostic features for cervical cancer detection. Cervicography [5] is analogous to VIA; in which images of cervix are acquired before and after the application of acetic acid. These images are sent to the experts who evaluate these images. The accuracy of evaluation is dependent on the expertise level of the evaluator and is highly subjective. The advances in digital imaging have enabled the acquisition of high quality cervix images at low cost. In addition, advances in image processing techniques have facilitated processing of these images using computerised tools thus can be used to compensate for the lack of expertise in low resource regions. Such automated image analysis system for cervix images can eliminate the subjectivity and improve the accuracy. Automated image analysis system for cervix images aims at identifying diagnostic features like acetowhite lesions, vascular abnormalities such as mosaics and punctations. There are various challenges for the extraction of acetowhite regions present in the cervix images. One of them is presence of Specular Reflections (SR) in the image. The specular reflections are bright white regions present on the cervix image. They are caused due to reflection of light from wet surface of the cervix. It is important to eliminate SR which otherwise would interfere in the detection of acetowhite regions. The cervix images may contain regions like vaginal walls, medical instruments and cotton swabs, which are not needed to be analysed. In addition, color and texture of these regions sometimes mimic the diagnostic features. Hence, it is desirable to identify the cervix region, which defines the Region of Interest (ROI) for cervix image analysis. An example of cervix image with various regions is shown in Fig. 1.

Specular reflection detection was dealt in many ways by the researchers [6–10]. Holger Lange [6] extracted a feature image, followed by adaptive thresholding to detect the SR. Zimmerman G et al. [7] utilised intensity, saturation and gradient information to detect the SR. Othmane E M et al. [8] filtered the image, converted filtered image into XYZ color plane and used luminance component and normalised luminance component for detection of SR regions. Abhishek Das [9] et al. extracted white pixels from red, green and blue channel and applied a logical AND operation on them to get the SR mask. Bianca Regeling [10] et al. used boxplot method for identification of SR on hyperspectral larynx images.

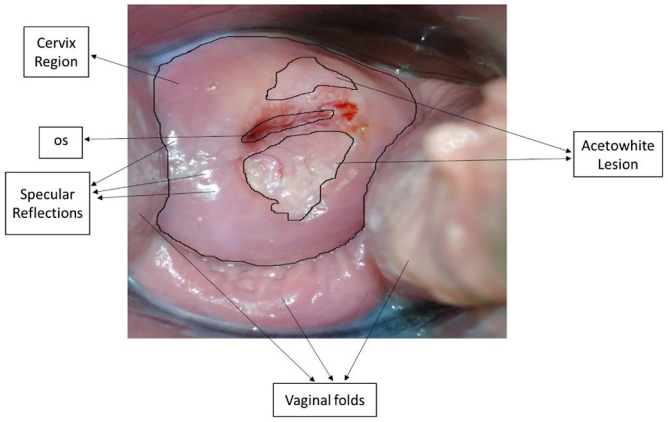

Fig. 1. Cervix image.

In literature ROI was detected based on color, position, curvature and shape features. Wenjing Li et al. [11] filtered the RGB image and applied Karhunen–Loeve (K–L) transform, followed by expectation maximisation algorithm to get the cervix region. They reported the extension of this work in [12]. In this work they eliminated the portion of vaginal folds present in the cervix region extracted in [11] using curve fitting [13]. A combination of color and position features were used for coarse ROI detection [14–18]. The cervix region detected using this method could not eliminate the vaginal walls completely. Accurate cervix boundary was detected using active contours based on curvature and color features [19,20]. Cervix region commonly takes the shape of an ellipse or a circle. Shelly Lotenberg et al. [21] used the shape information to segment the cervix region. Shape models (ellipse and circle) were embedded in active contour framework to segment the cervix region. Costas P. et al. [22] proposed an automated method for enhancing and identifying partial curvilinear structure on geophysical images. We propose an algorithm for SR detection using a standard deviation filter and cervix region segmentation algorithm by adapting the curvilinear structure enhancement suggested in [22].

2. Materials and methods

2.1. Data collection and ground truth

Color images of the cervix were acquired in screening programs at the health centres, conducted by Kasturba Medical College, Manipal, Karnataka, India. Married women above 25 years of age were considered for the study. Informed consent was obtained from the women participating in the study. 151 images of cervix were acquired one minute after the application of acetic acid using a Moto G Turbo cell phone with 13 MP camera. The ROI was manually annotated in all these images by a medical expert in the field of cervical cancer screening.