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# Automatic Detection and Inpainting of Specular Reflections for Colposcopic Images

**Research Article**

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**Abstract:** Specular reflections are not wanted in images because they can really reduce the performance of image processing techniques. This is particularly true for medical images and especially for colposcopic images. There are several methods in the literature allowing to extract specular reflections, but only a few methods can perform an automatic extraction. In this paper, we propose a new method to extract and to restore specularities automatically. This method is based on Dichromatic Reflection Model (DRM) and multi-resolution inpainting technique (MIT). The DRM approach will retrieve specularities while the MIT technique re-establish colors in bright zones using local information. The proposed method achieves good results and does not need any a priori knowledge. The efficiency of this method for colposcopic images has been demonstrated through a collaboration with the oncology center of Marrakech University Hospital.

**Keywords:** colposcopy • inpainting • specular reflections • dichromatic model



## 1. Introduction

Cervical cancer is one of the most common cancer affecting women worldwide and the second most common in less developed countries [1]. More than 500,000 new cases diagnosed each year and approximately half of these patients will die later [2]. This cancer appears on the tissue localized in the lower part of the uterus commonly called the cervix. It proliferates through the cervical tissue starting with abnormal cell changes and can degenerates gradually into cancer [3]. Colposcopy is a clinical exam to detect cancerous and pre-cancerous cells through visual check of the

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cervix [4]. During the colposcopic exam, 3% to 5% of acetic acid solution is applied to the cervix area. The tissue that appears grossly normal but turns white after acetic acid application is called acetowhite epithelium. Physicians evaluate the color density of the acetowhite regions to determine the severity of tissue lesions. They examine color changes through a colposcope, save some interesting images, reports their findings and, if necessary, recommend a biopsy to confirm the diagnosis. During the examination, several specular reflections may appear;this can affect the diagnosis during the colposcopic exam and can significantly decrease the performance of colposcopic images processing methods such texture analysis and image registration techniques. Actually, the issue of removing specular reflections is intensively investigated in several medical imaging fields. Oh et al. [5], detect specular reflections by introducing two classes of regions: regions with intense bright called *absolutely bright* regions and regions with moderate bright called *relatively bright* regions. The union of both regions are considered as the set of specular reflections. Arnold et al [6] propose a segmentation method of specular reflection based on nonlinear filtering and color image thresholding. In thoracoscopy, Saint-Pierre et al. [7] suggest to apply non linear filter to increase the gap between specular and non specular reflections. Then, they localize the specular bump in the image histogram (last pic in the histogram) allowing to get a threshold to extract specular reflections.
Regarding to the colposcopic images, many approaches have been proposed, Lange [8] proposes to exploit the green (G) channel of the RGB color space to detect saturated regions. These regions are extracted by using an adaptive threshold to determine the position of the last pic in the histogram corresponding to the green channel. Zimmerman et al. [9] propose an approach based on Intensity and Saturation channels of the HIS color space representation. This approach exploits the fact that in specular reflections, the intensity channel value is high while the saturation channel value is low; therefore it would be easier to distinguish between reflection and non reflection regions. This approach models specular reflections by using Gaussian mixture models; they respectively use two and four Gaussian distributions to describe specular and non specular reflections. This method requires an a priori knowledge about the number of Gaussian distributions; this is inconvenient because in many cases, this number is not known. In [10], Hervet et al. propose a semi automatic segmentation method based on two steps: in the first step, images are segmented by quantifying color information; in the second step, a spatial segmentation is accomplished by a region growing method. Then, a histogram transform (histogram equalization) is applied on manually selected frames (frames include highlight and normal tissue) in order to eliminate specular reflections. But this method has a drawback: color segmentation results are not always correct because they are usually disturbed by highlights.
In this paper, we present a method based on the Dichromatic Reflection Model. This method exploits the chromatic proprieties of highlight areas. The application of this model is justified by the nature of colposcopic images which are characterized by uniform colors, slightly textured and homogenous zones. In addition, the proposed method does not require any manipulating threshold. This avoids to estimate the optimal threshold value which is usually a difficult task. The paper is organized as follows: the Dichromatic Reflection Model is briefly explained in Section 2. The proposed method to extract specular reflections is presented in Section 3. The inpainting approach is described in Section 4. In Section 5, we show experimental results. Section 6 concludes the paper and gives an overview on the future work.

## 2. The Dichromatic Reflection Model

In this section, we will describe the Dichromatic Reflection Model approach [11] we use to characterize specular reflections. This approach supposes that color information in an image is the sum of two components; one being the diffuse reflection and the other, the specular reflection. The diffuse reflection carries the color of the object's body while specular reflection displays the surface reflection body. Following this model, the information $L(\lambda, \theta_i, \theta_r, g)$ measured by the camera sensors can be written as [11]:

$$L(\lambda, \theta_i, \theta_r, g) = L_{diff}(\lambda, \theta_i, \theta_r, g) + L_{spec}(\lambda, \theta_i, \theta_r, g) \quad (1)$$

where:
- $L_{diff}(\lambda, \theta_i, \theta_r, g)$ is the diffuse reflection term
- $L_{spec}(\lambda, \theta_i, \theta_r, g)$ is the specular reflection term
- $\theta_i, \theta_r$ and g are the geometric parameters. They describe respectively the incidence angle of the light source, the viewing angle and the phase angle.
- $\lambda$ is the wavelength parameter

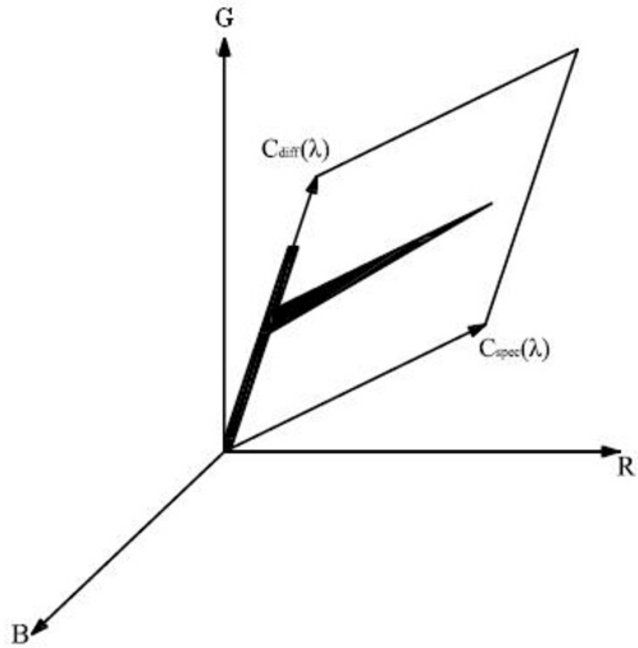



**Figure 1.** A dichromatic plane in RGB space.

Equation (1) can also be written as follows [11]:

$$L(\lambda, \theta_i, \theta_r, g) = m_{diff}(\theta_i, \theta_r, g)c_{diff}(\lambda) + m_{spec}(\theta_i, \theta_r, g)c_{spec}(\lambda) \tag{2}$$

where $m_{diff}$ and $m_{spec}$ are respectively the weight factors of the diffuse and the specular reflections. These factors depend only on the geometric parameters $\theta_i$, $\theta_r$ and g. The terms $C_{spec}(\lambda)$ and $C_{diff}(\lambda)$ called respectively surface reflection and the body reflection components describe how the color distribution of the incident light is modified by the two different types of reflection. In RGB color space representation, this distribution out to a "T" shape, where the horizontal bar of the "T" corresponds to body reflectance, and the vertical bar to the surface reflectance, as shown in Figure 1.
In this paper, we use the CIE-xyY space color representation. This choice is justified by the fact that CIE-xyY color space can describe color and brightness independently. The chromaticity coordinates x and y are obtained from the CIE-XYZ representation by the following transformation:

$$x = \frac{X}{X + Y + Z} \tag{3}$$

$$y = \frac{Y}{X + Y + Z} \tag{4}$$

The figure below shows the related chromaticity diagram in which all visible colors are represented [12]. In this diagram, the white zone (centered region) called achromatic region is characterized by maximum luminance ($Y$) and colors have low chrominance while the edge of the curve corresponds to pure colors. Commonly, physicians use white light to illuminate the brain tissue. To have an idea about the influence of white light on colors reflected by surface and body reflection, we have to project the "T" shape of each point in the chromaticity diagram. A pixel will be considered as a reflection point if its luminance is maximal and its chrominance is lower than its luminance.

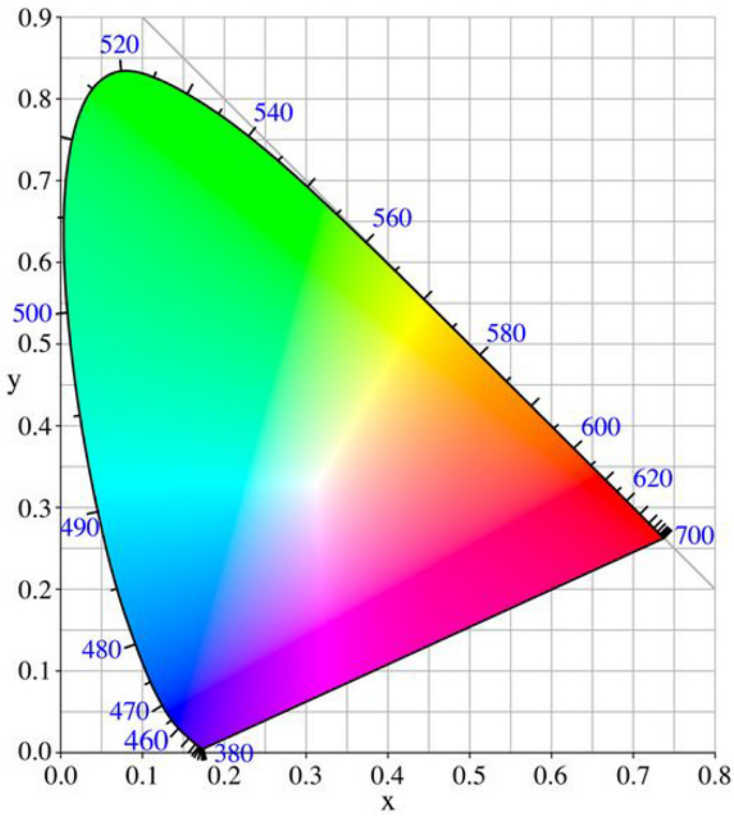



**Figure 2.** The CIE-xyY chromaticity diagram.

## 3. Extracting specular reflections

In order to extract specular reflections, we look for pixels having luminance component greater than their chromatic luminance. To achieve this task, we propose a method based on three main steps. The first step consists of enhancing the specular reflections. In the second step, the image is converted from CIE-RGB to CIE-XYZ representation space, then, the chromatic luminance $y$ is computed from CIE-XYZ representation by using the equation (4). Finally, pixels having a chromatic luminance lower than their luminance ($Y$) are extracted. Figure 3 described the complete implemented process.

### 3.1. Reflection enhancement

Colposcopic images are not easy to analyze since there is small difference between the appearance of pale-colored tissues and specular light reflections. To increase this difference, a non linear filter is applied to the image in the following way:

$$\begin{pmatrix} R' \\ G' \\ B' \end{pmatrix} = \frac{min(R,G,B)}{max(R,G,B)} \begin{pmatrix} R \\ G \\ B \end{pmatrix} \tag{5}$$

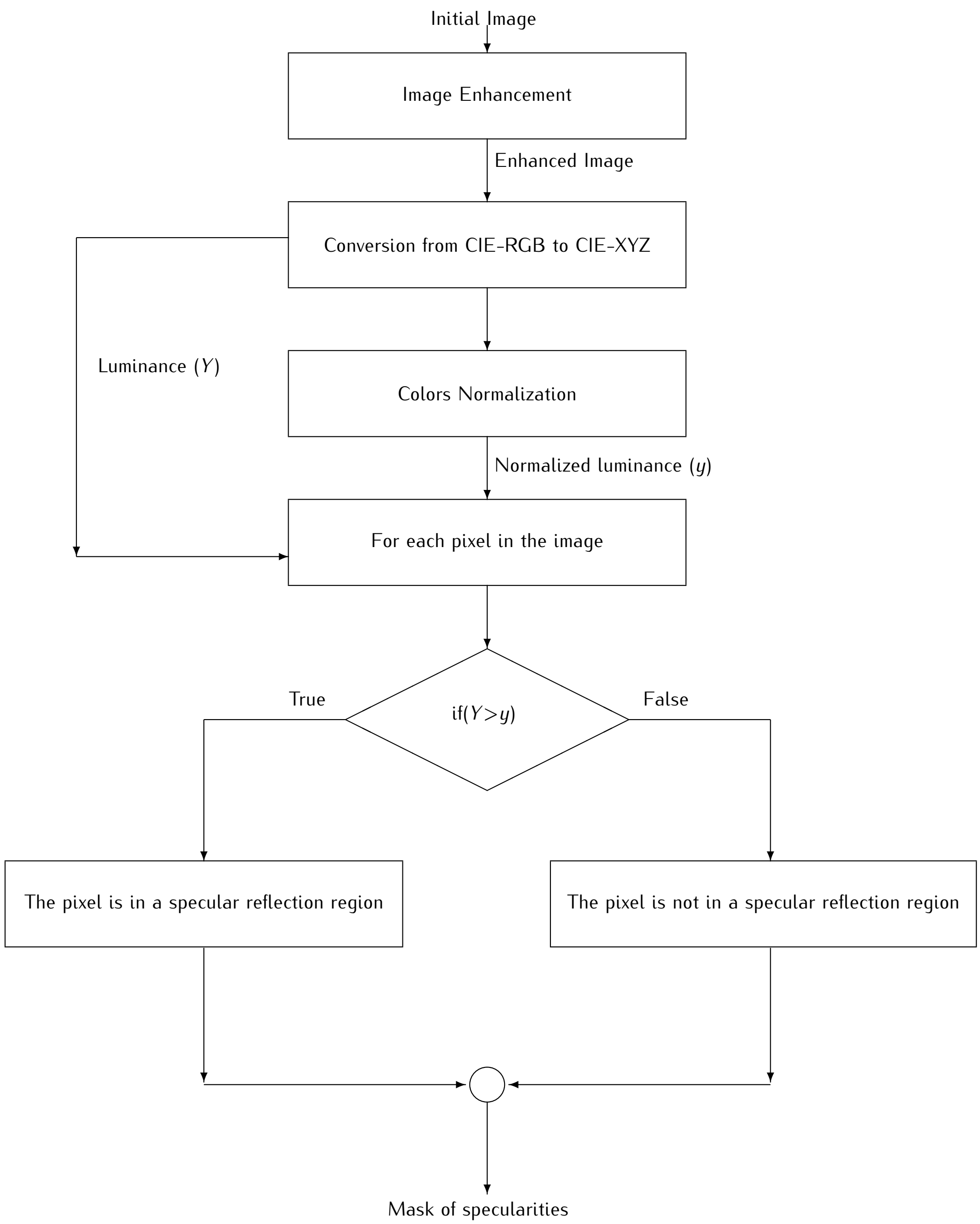



**Figure 3.** Diagram of the proposed algorithm.

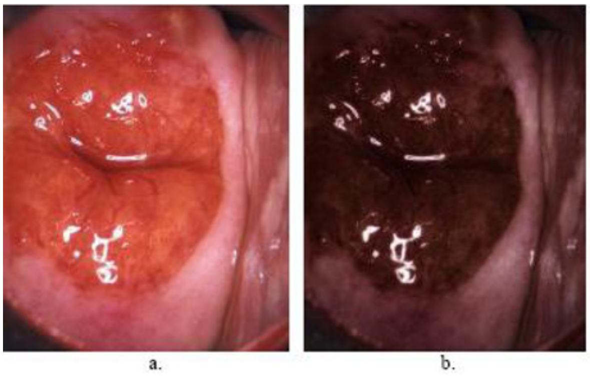


**Figure 4.** Effect of applying a non-linear filter to a colposopic image a. Initial image b. Enhanced image.

where $\begin{pmatrix} R' \\ G' \\ B' \end{pmatrix}$ is the filtered image. Figure 4 shows an example of the effect of applying this filter.

### 3.2. Computing luminance and chromatic luminance

To evaluate the brightness value, we begin by computing the luminance of the color image. This luminance is derived from the conversion from CIE-RGB to CIE-XYZ. In CIE-XYZ space, $Y$ is defined as follows:

$$Y = 0.2126 \times R + 0.7152 \times G + 0.0722 \times B \tag{6}$$

Then, we compare the luminance and the chrominance of each pixel. Thus, we calculate the chromatic luminance from RGB normalized values, as follows:

$$y = 0.2126 \times r + 0.7152 \times g + 0.0722 \times b \tag{7}$$

$r$, $b$ and $g$ are the normalized values determined from RGB space.

### 3.3. Extracting Mask of specularities

The last step consists on comparison between luminance and chromatic luminance. Pixels satisfying the inequality $Y < y$ (the chromatic luminance is lower than luminance) are considered like points belonging to specular reflection. Figure 5 shows an example of mask describing specular reflection obtained with this automatic detection algorithm.

## 4. Inpainting specular reflection

Image inpainting is the process of reconstructing lost or deteriorated regions in image or in video sequence. In our case, deteriorated regions are specular reflections. Many techniques have been applied in medical imaging field to remove specular reflections. Saint-Pierre et al. [7] use inpainting method proposed in [13] to reconstruct lost information inside specular reflection regions in digital thoracoscopic images. In colposcopic image domain, two approaches have been proposed in the past. The first approach suggested by Zimmerman et al. [9] is based on applying a filter allowing to each pixel within specular reflection region to have a value computed from the mean colors of its neighbor pixels belonging to non specular reflection. In the second method [8], glare regions are removed by filling specular reflection pixels with an estimate of the underlying image colors using Laplace equation.
All these methods are based on gradual propagation of colors from edges toward the specular reflection center; therefore, they provide good results when specular reflections cover small areas. For colposcopic images, glare regions with large sizes are current; subsequently, it is not realistic to reconstruct lost information by only considering the propagation

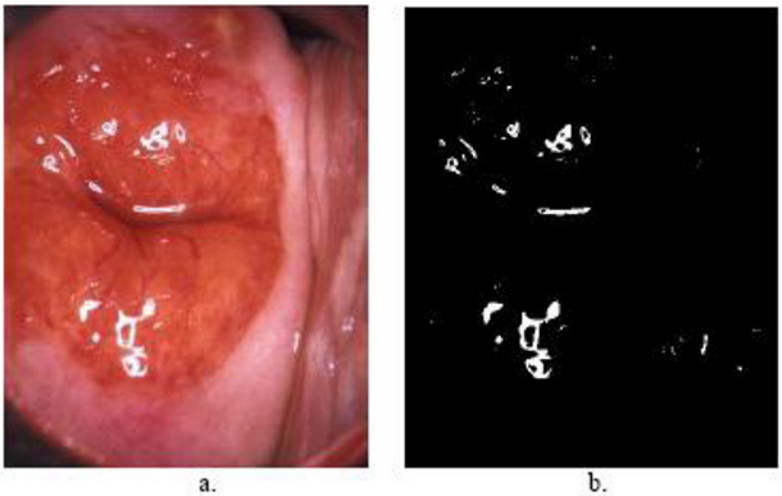



**Figure 5.** Obtained mask using the proposed method: a. Initial image b. Mask of specularities.

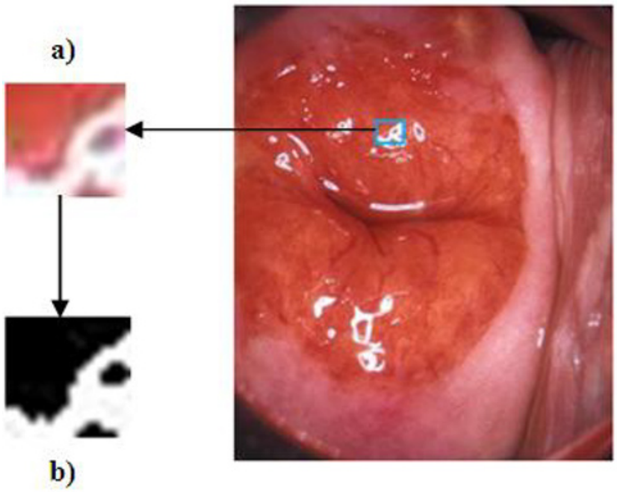



**Figure 6.** Example of a block containing reflection: a. Initial block b. Extracted mask using proposed method

of neighboring pixels information. To deal with this issue, we propose a multi-resolution technique based on three steps; first, specular reflection masks are extracted by using the method described in Section 3; in the second step, the method proposed by Shih et al. [14] is used to correct specular reflection areas; finally, a histogram transform is applied to eliminate the blocks effect and to ensure that reconstructed regions are more similar to neighboring regions. The three-step process is explained as follows:

1. *Step 1*:
   In this step, specular reflections masks are extracted, then the image is divided into small blocks. Only blocks including specular reflection will be addressed. An example of a block with reflections is shown in Figure 6.

2. *Step 2*:
   Glare regions are restored in the first stage by using a multi-resolution technique proposed in [14]. This method takes into account different level of details in an image. After extracting blocks with specularities, the color variance of each block is computed; if it is greater than a given threshold, the bloc is divided into two parts; otherwise, we calculate the percentage of bright pixels, and finally depending on its value, we replace highlights

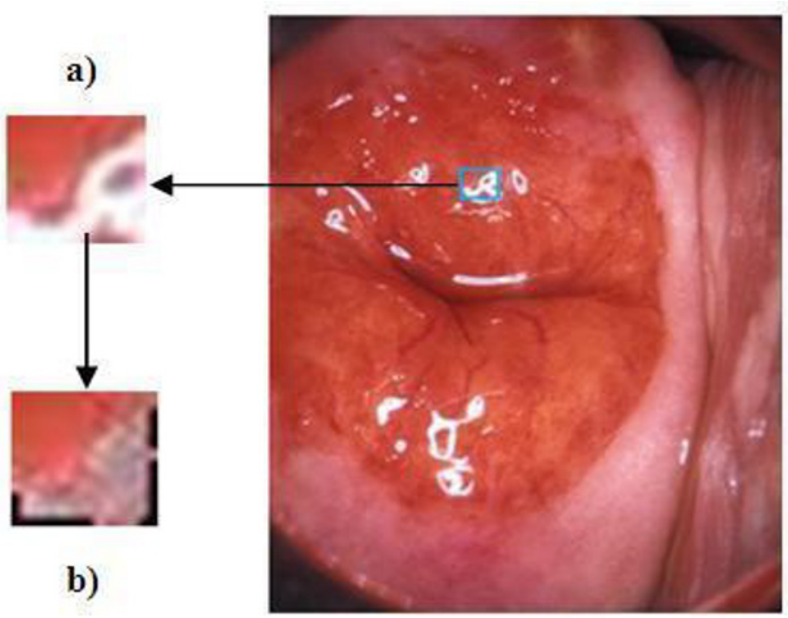



**Figure 7.** Example of result obtained using the method proposed in [16] a. Initial block, b. Result of correction using step 2.

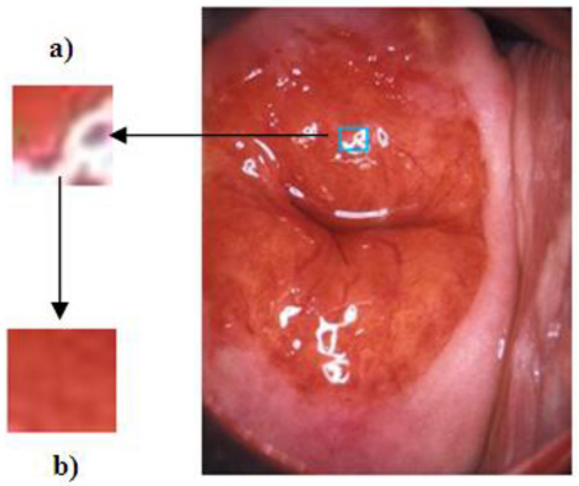



**Figure 8.** Example of result obtained using histogram equalization: a. Initial block, b. Result of correction using step 3.

pixels by either the average of blocks with a given size or with neighboring pixels (for more details, see Shih et al. [14]). An example of restored block is shown in Figure 7.

3. *Step 3*:

   In this step, a histogram equalization is applied to each block restored in the previous step. This process allows to homogenize restored blocks regions with neighboring regions and to reduce the effect caused by partitioning the image in several blocks. An example of correction using step 3 is shown in Figure 8.

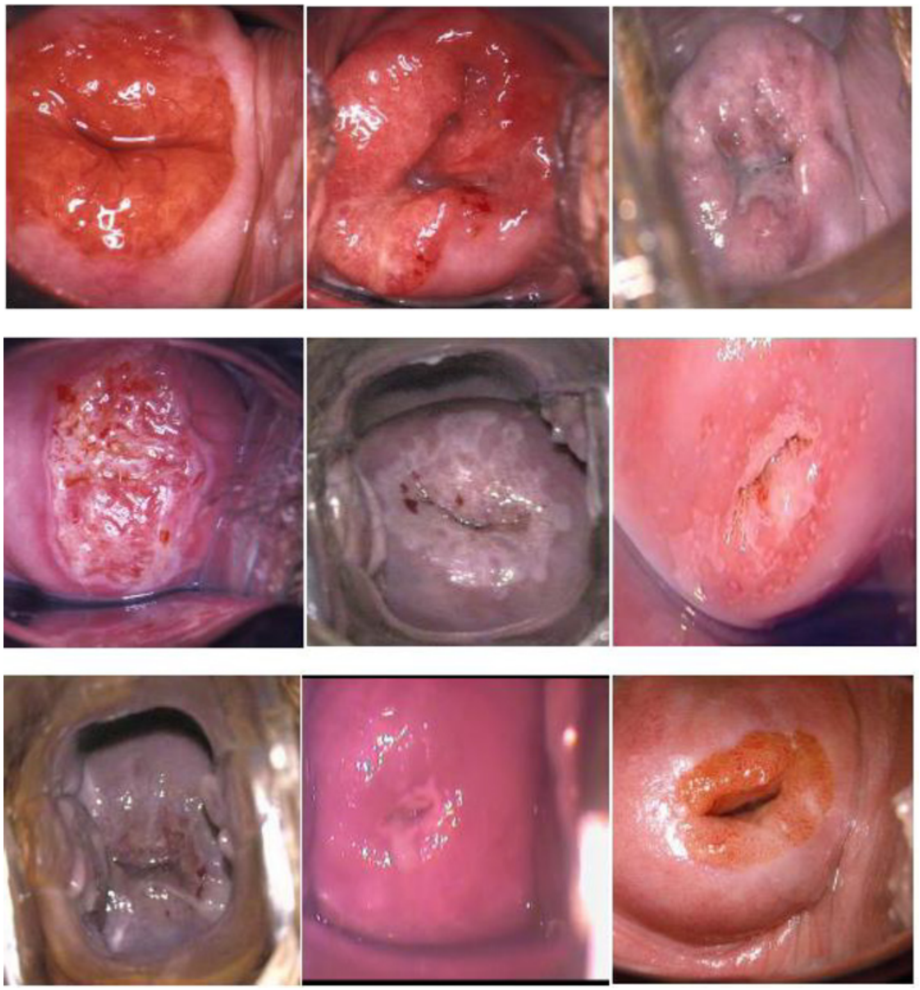


**Figure 9.** A sample set of Images collected to evaluate the proposed method.

# 5. Experiment results

## 5.1. Extraction of specular reflections

This section gives some experiment results to evaluate the proposed method. For this purpose, a large database with a variety of colposcopic images was collected in collaboration with a physician. This database is composed of 286 images: 106 images are extracted from a series of 18 different videos sequences and 180 isolate images which are taken during the colposcopic examination. Figure 9 shows a sample of images from this database.

To evaluate the proposed method, we collaborate with a medical expert in order to have a large variety of colposcopic images. Our aim is to have a collection of images including images with normal tissue, images with acetowhite area and images with cervical cancer. After building the database, we use the algorithm described in Section 3 in order to extract specular reflections. We also employ a classic method [7] for comparison with our method. Figure 10 shows an example of two colposcopic images with normal tissue, Figure 11 and Figure 12 shows respectively the results obtained with both approaches for the two images.

Visually, we noted that the proposed method provides much better results than the method in [7]. To go further, we test our method on more complex images where it is not easy to differentiate between specular reflection and surrounding tissue. Figure 13 shows an example of such images. Figure 14 and Figure 15 shows respectively the results obtained with both approaches for the two images. Here also, the proposed method performs better especially for the image b.

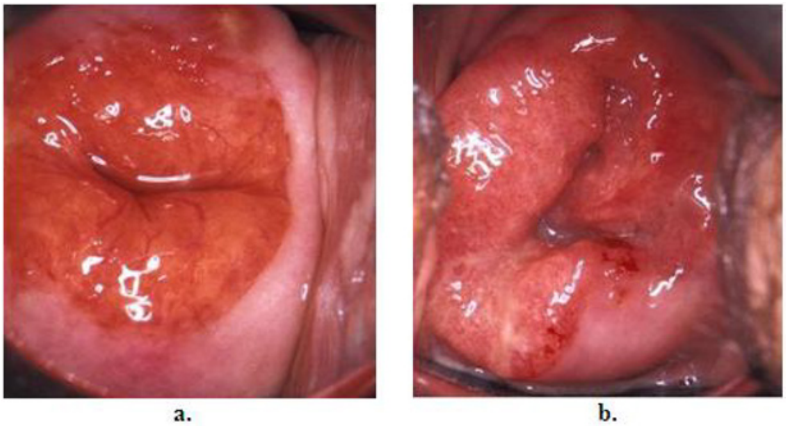


Figure 10. Two colposcopic image with normal tissue.

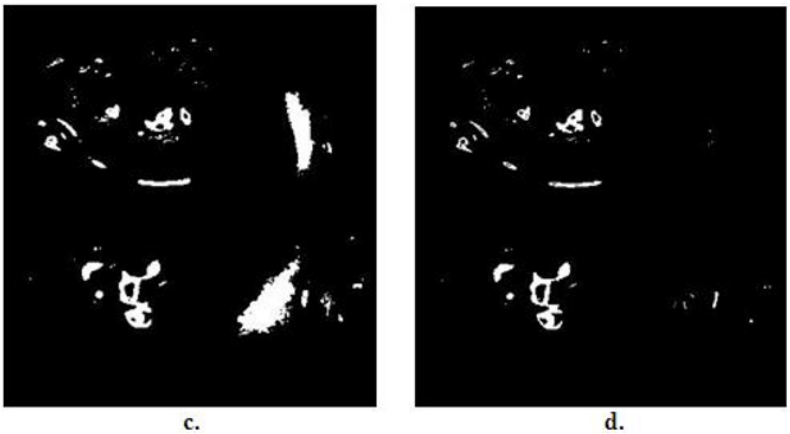


Figure 11. Specular reflection mask obtained for the image a. Figure 10: c. Classic method, d. Proposed method.

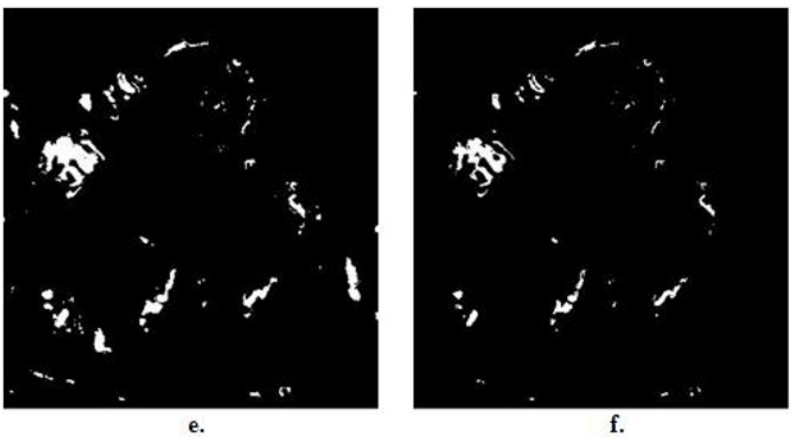
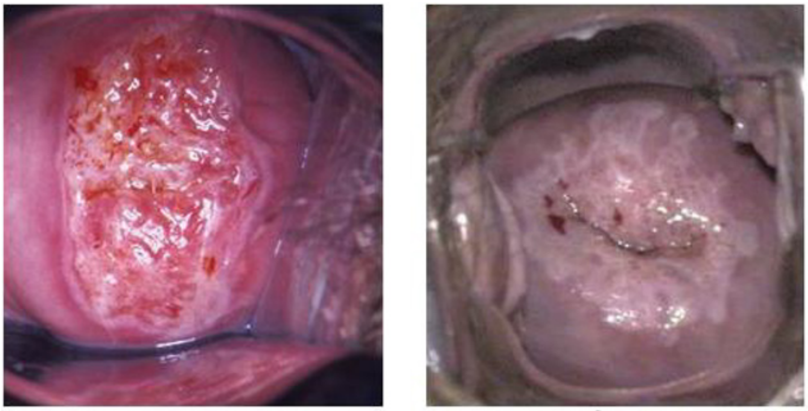
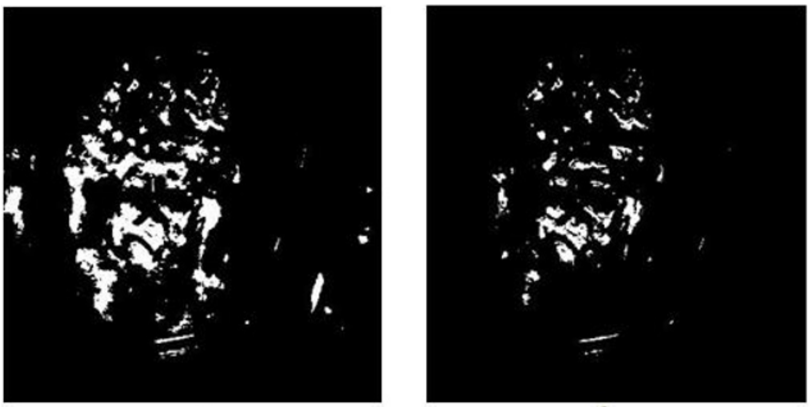


Figure 12. Specular reflection mask obtained for the image b. Figure 10: e. Classic method f. Proposed method.



a. b.

**Figure 13.** Two colposcopic image: a. image with abnormal tissue b. images with acetowhite area.



c. d.

**Figure 14.** Specular reflection mask obtained for the image a. Figure 13: e. Classic method, f. Proposed method.

Figure 15, where the classical method perceives the acetowhite area as a reflection zone.
Finally, we ask a medical expert to choose some interesting images from our database and to give a subjective opinion regarding specular reflections results to compare our method and the proposed method in [7]. He was requested to provide a mark on a scale going from 1 to 5 (1 being strongly disagree and 5 being strongly agree). Table 1 shows the score of this investigation done on database containing 52 images.We note that by the proposed method we get 37 images with a score equal to 5 or 4 which constitutes a rate of 71% and 27 by the [7] method which constitutes 52%. Here also, the proposed method performs better. The 71% score can be considered as an excellent score because of the diversity and the complexity of these images.

**Table 1.** Grading statistics for detection.

| Quality | Number of images obtained by the Saint-Pierre method | Number of images obtained by the proposed method |
|---|---|---|
| 1 | 5 | 1 |
| 2 | 9 | 3 |
| 3 | 11 | 11 |
| 4 | 20 | 27 |
| 5 | 7 | 10 |

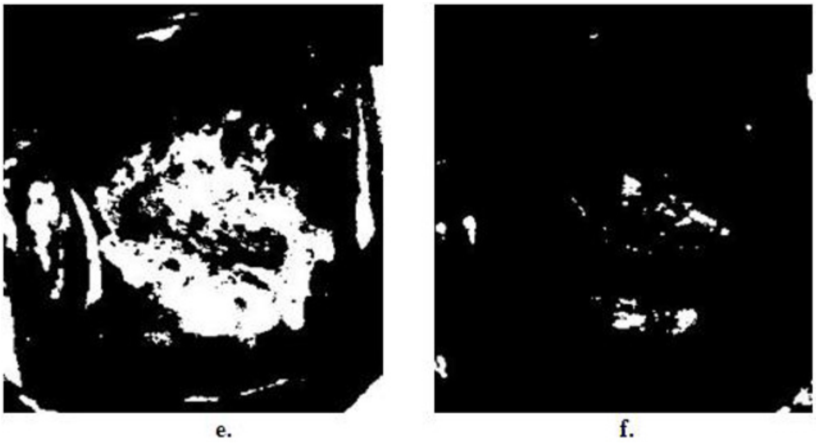


Figure 15. Specular reflection mask obtained for the image b. Figure 13 e. Classic method, f. Proposed method.

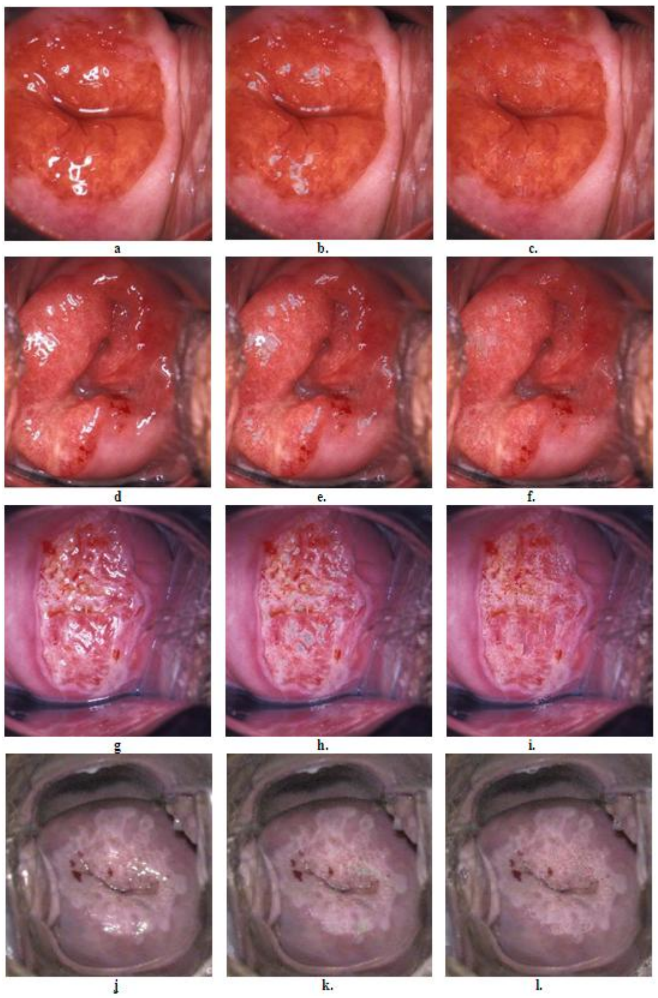


Figure 16. Examples illustrating the performance of the inpainting algorithm; the first column : the original images, the second column: inpainted images using the method presented in [14], the third column: the results of the proposed method.

### 5.2. Restoration of specular reflections

We implemented the inpainting algorithm described in Section 4 using a MATLAB programming language. We divided each image into blocks, then we extract the mask using the method described in Section 3. If a block contains specular reflections, it will be restored using step 2. During this step, a multi-resolution technique is applied in each block by computing the rate of reflections in this block; depending on the value of this rate, the block will either be divided or not [14]. The Figure 16 column 2 shows some results obtained by using step 2. As shown, there are darker areas in some corrected reflection zones. This darkness can be explained by the fact that for colposcopic images, black areas are often located at the border between the colored tissue and the reflection zones. One option to solve this problem is to remove these areas by applying a dilatation filter in the initial image. This method fails, especially if glares are located in the borders of two non-similar cervix regions. In order to address this problem, we use a histogram equalization(step 3, Section 4). Column 2 and column 3 Figure 16 displayed respectively restored regions before and after equalization. We note in images viewed in column 3, that darkness has been removed and corrected regions are very similar to neighboring regions.

## 6. Conclusion

In this paper, we have presented a new fully automatic method to extract and restore specular reflections in colposcopic images. The major idea of the proposed method is to exploit chromatic proprieties of specular reflections zones. This is accomplished by comparing luminance component y of the normalized CIE-xyY space and the luminance Y of the CIE-XYZ space. The restoration of reflection regions is done by a multi-resolution inpainting technique based on local information. The performance of the method on a database including a large diversity of colposcopic images is very promising. In the future, we plan to investigate image retrieval and image registration research fields. Stages of removal and restoration specularities were required before performing any image registration or image retrieval technique.

## 7. Acknowledgments

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