

Specular Reflection Identification

In image processing, the color space refers to a specific way of representing and organizing colors in images. It is a mathematical model that maps numerical values of color components to the visual perception of colors. The color spaces provide a framework for manipulating, analyzing, and interpreting color in digital images. There are several color spaces with distinct characteristics, and the choice of color space depends on the particular application. This chapter uses color space models to recognize the SR region on smart colposcopy images. This chapter explores various color spaces to ascertain the most suitable one for identifying the SR region on smart colposcopy images. Once the appropriate color space is identified, proposed an approach using the intensity-based threshold method to locate the reflection region in the cervix images. The suggested method is compared to existing methods, and a performance analysis is conducted in this chapter. Additionally, the proposed approach is employed on other medical images to evaluate the performances further. By analyzing the performance of different color spaces and applying threshold techniques, the chapter aims to improve the identification of SR regions in medical images, specifically in smart colposcopy images.

4.1. Existing Method for the Identification of Specular Reflection on Colposcopy using Color Space

This section explores existing methods for detecting reflection regions in “*smart colposcopy images*” using the color space model. The existing methods discussed in this session are the adaptive threshold method, the chrominance and luminance-based threshold method and the Fusion method. The adaptive threshold method uses the HSV color space model to identify the reflection region. The chrominance and luminance-based threshold method uses the XYZ color space model to detect SR on the colposcopy images. The fusion method combines the color channel of three-color space models to detect the reflection region on the images.

4.1.1. Adaptive Threshold for Specular Reflection Detection

This method identifies the SR pixel on the smart colposcopy images using the HSV color space model. The HSV represent the Hue Saturation Value where the S and V have

high intensity and low saturation values, similar to the SR properties. Because of these properties, it is used in many medical images to identify the reflection region. Typically, the H doesn't contain any details about the SR because it only indicates the depth of the colors. But in this method, each channel of the HSV hue space is utilized to detect the reflection region. Even though the Hue channel does not provide any information about SR, it has some white pixels that affect the pure colors of the cervical images [67]. The steps involved in the detection of SR from the colposcopy images using adaptive threshold methods are as follows:

Step 1 : RGB color images are transformed to the HSV color space.

Step 2 : Each channel is analyzed to produce the three matrices like " H , Σ and Y ". The operations are applied to extract the H , Σ and Y to enhance the detection quality. The detailed processing of all channel is discussed as follows:

H-Channel

1. A 3x3 patched matrices is extracted for each pixel of the H channel.
2. Local variation of the patch's central pixel is calculated and displayed via the patch variance.
3. The local variances are normalized to extract the H matrix from the H channel.

S-Channel

1. The S channel is normalized and then a unit shift is applied on the S channel.
2. The ramp function is applied to remove the negative values from the normalized value to extract Σ matrix from the S channel. It indicates that strong reflections are likely to occur at lower saturation values.

V-Channel

1. The V channel is normalized, and then a unit shift is applied on the V channel.
2. The Ramp function is applied to remove the negative values to extract Y matrix from the V channel. It indicates that higher values of V would probably have bright reflections.

Step 3: The three matrices (i.e., H , Σ and Y) are aggregated to extract the cost function as represented in the equation (4.1).

$$\text{Costfunction} = H + \Sigma * Y \quad (4.1)$$

Step 4: The statistically constant function is applied to detect the threshold value as in equation (4.2)

$$t_0 = \mu + k * \sigma \quad (4.2)$$

The K represent the constant value (i.e., 4.5), the threshold value used to detect the SR based on the image's pixel values. The pictorial representation of the steps required in the identification of SR region is represented in the Figure. 4.1.

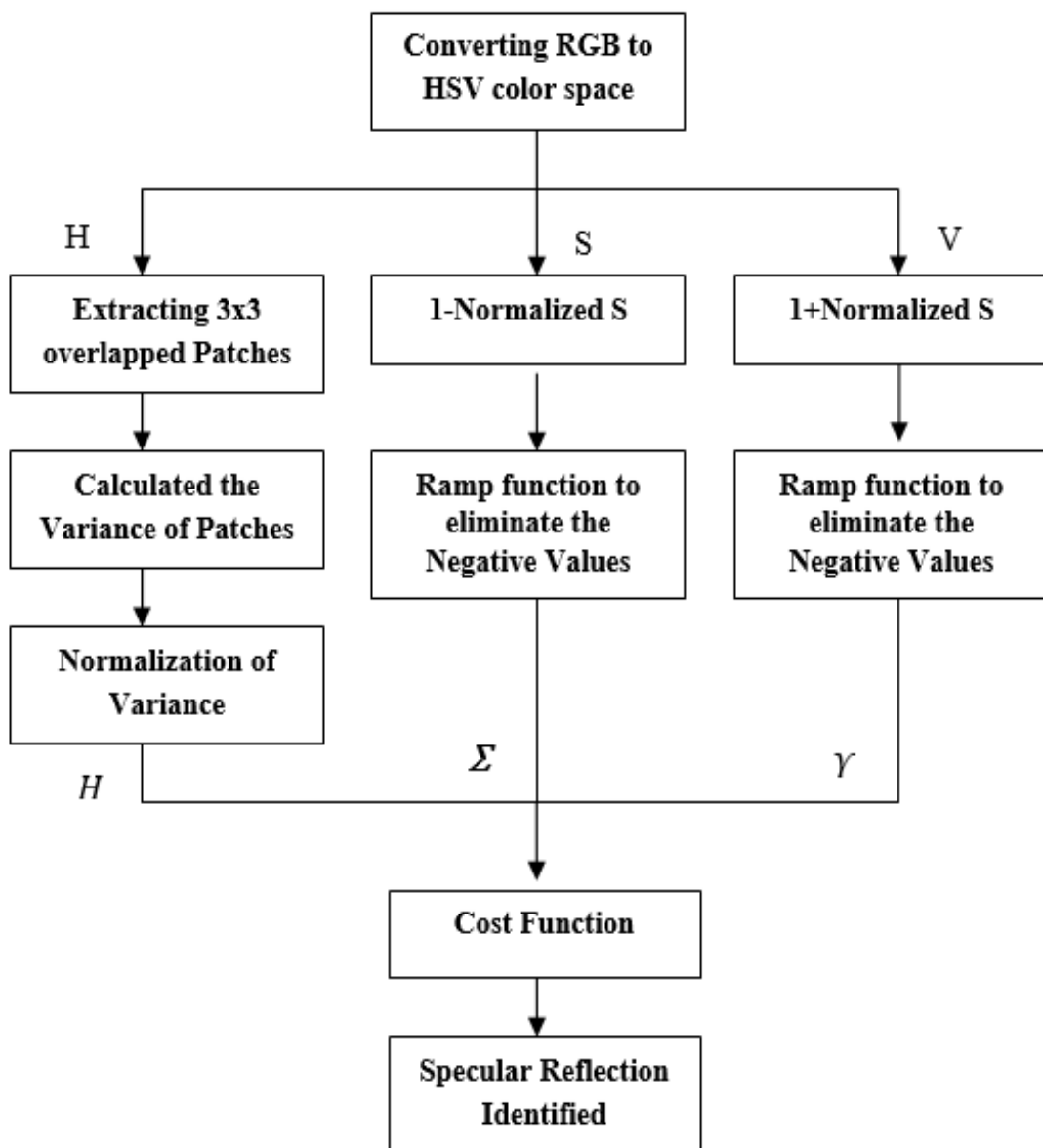


Figure 4.1 Adaptive Threshold Method for the Identification of Specular Reflection

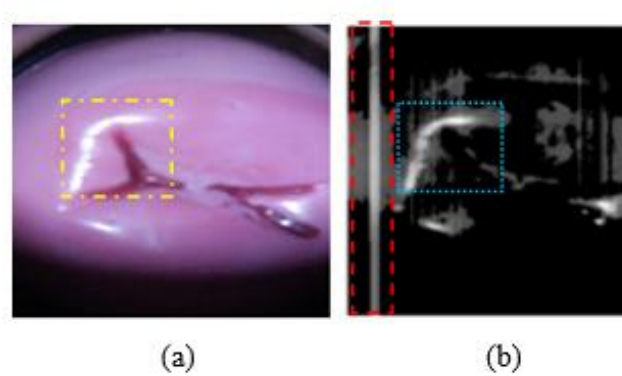


Figure 4.2 Identification of SR using Adaptive Threshold Method. (a) Original Image with specular reflection (Yellow Marked) (b) Reflection identified using adaptive threshold method. Red Box represented the damaged pixel during the reflection identification process and Blue Box represent the reflection region identified using Adaptive Threshold Method

The disadvantage of this method is that along with SR, some of the non-SR regions are identified as reflections on the cervix images. This method also damages specific pixels in the images, influencing the standard of the images as represented in the Figure. 4.2. This method degrades the quality of the images by damaging some pixels on the images, which in turn leads to difficulties during the analysis of the colposcopy images.

4.1.2. Chrominance and Luminance-based Threshold Method for Specular Reflection Identification

The chrominance and luminance-based threshold method uses the XYZ color space to determine the SR on smart colposcopy images. The CIE-xyY and CIE-XYZ are employed to detect specular reflection on the colposcopy images because of its brightness properties used [65]. From the CIE-XYZ, the chromaticity parameters x and y are taken out and converted into equations (4.3) and (4.4).

$$X = \frac{X}{X+Y+Z} \quad (4.3)$$

$$y = \frac{Y}{X+Y+Z} \quad (4.4)$$

The chrominance and luminance properties are used to identify the reflection region from the colposcopy images. If the luminance value (Y) exceeds the chrominance value (y), the pixels belong to the SR region, as shown in Figure 4.3 The steps involved in the detection of SR from the cervix images using the XYZ-based method are:

Step 1: Enhancement processing is employed to the colposcopy images using the equation (4.5) to differentiate the color of the tissue in the cervix images.

$$\begin{pmatrix} R' \\ G' \\ B' \end{pmatrix} = \frac{\min(R,G,B)}{\min(R,G,B)} \begin{pmatrix} R \\ G \\ B \end{pmatrix} \quad (4.5)$$

Step 2: The enhanced images are converted to XYZ color space to extract the channel Y, i.e. the luminance value of the pixels.

Step 3: The color normalization is applied on the XYZ color space to extract the channel y, i.e. the chrominance value of the pixels.

Step 4: If the luminance of the pixels value is exceeding the value of chrominance, the pixels belong to the SR, and the remaining pixels belongs to the non- SR regions

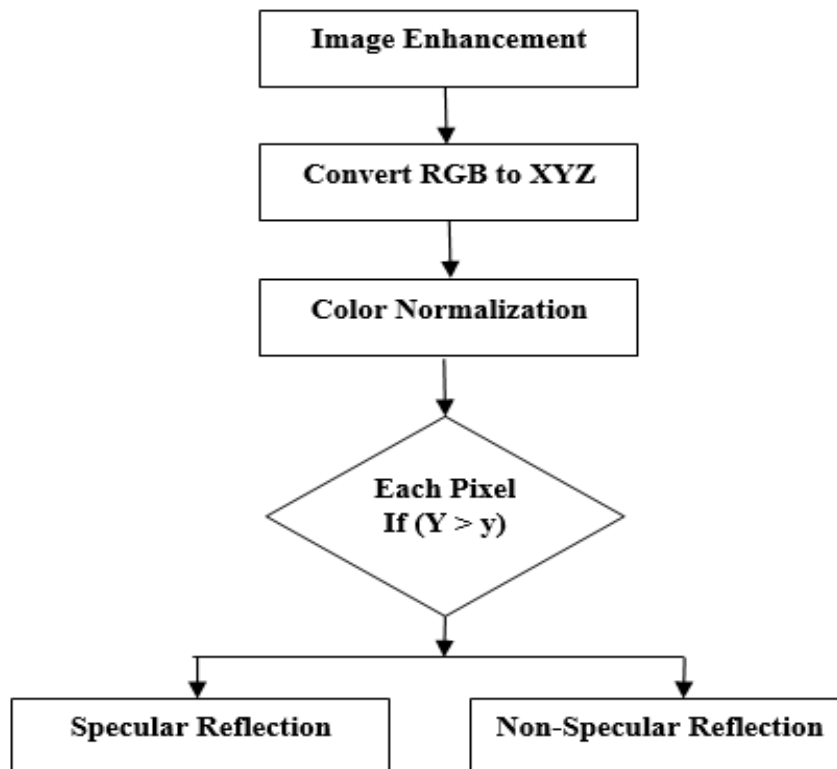


Figure 4.3 Chrominance and Luminance-based Threshold Method for Specular Reflection Detection

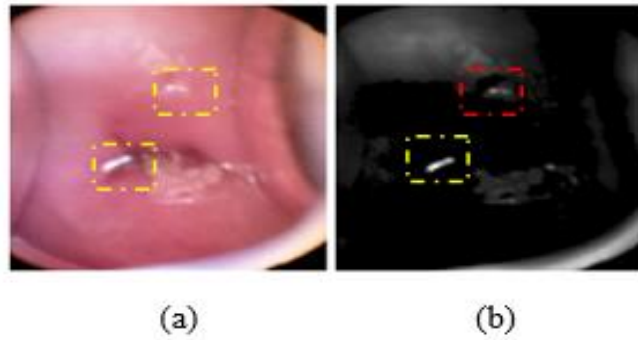


Figure 4.4 Identification of Specular Reflection using Chrominance and Luminance-based Threshold Methods. (a) Original Image with specular reflection (Yellow Marked). (b) Reflection identified utilizing Chrominance and Luminance-based Threshold Methods

This method is applied to the colposcopy images gathered from the “*Kaggle dataset*”. On the context of analysis, it identifies the large SR region from the cervix images as represented in the Figure 4.4 (a-yellow box). However, this method does not detect some small-scale SR, as shown in Figure 4.4(b-red box). The red box represents the small-scale reflection region not identified in the images, which will cause difficulty during the inpainting process.

4.1.3. Fusion Method for Specular Reflection Identification

In the Fusion method the three-color space like HSV, RGB, and LAB are combined to identify the reflection region on the smart colposcopy images. In these color model, specific channels have the property to identify the SR because of its high-intensity value. From the RGB color space, Green (G) has the property to differentiate the SR without any computation process [72]. From HSV, S has similar properties of the SR, and in many colposcopy images, the $(1-S)$ function is used for higher detection of the reflection region. In LAB color space, L symbolize the lightness of images that detect SR regions from the colposcopy images. The channels with the higher property of SR are aggregated to acquire the feature images, as indicated in equation (4.6). The steps required in detecting the SR are discussed as follows:

Step 1: The feature images F from the cervix images are extracted using equation (4.6).

$$F = ((1 - s) * G * L)^3 \quad (4.6)$$

Step 2: The standard deviation filter is applied with the filter size of 3 on the feature images to normalize the image pixels where fi indicate the feature of the pixel values and f indicate the mean of the pixels using the equation (4.7).

$$\text{StandardDeviation} = \sqrt{\frac{\sum(f_i - f)^2}{m*n-1}} \quad (4.7)$$

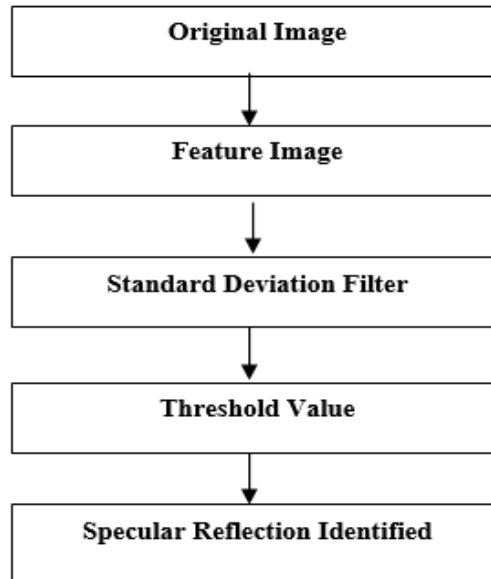


Figure. 4.5 Fusion Method for Identification of Specular Reflection

Step 3: Threshold value is obtained from the filtered images to detect the reflection region from the cervix images. The step involved in the identification of reflection is represented in the Figure 4.5.

The standard deviation filter normalizes the pixel count of the images from 0 to 1. The pixel value 1 shows the highest brightness region on the images. Threshold value 0.9 is utilized to detect the SR from the images. The detected reflections using this method are blurred and not evident during the analysis process. So, this method will make it more difficult to precisely identify and remove the SR regions in the images.

Based on investigation of the fusion method the reflections region identified are not clear and appear blurred, which is marked using the red box as represented in the Figure 4.6 (a). Along with the reflection some of the non-reflection region is also recognized in the smart colposcopy images. On analysis of the existing method, the non-reflection regions are also identified as reflections using the current method. It will cause the cervix photos' information to be lost, causing difficulty in analyzing the images and detecting the cancer cells from the colposcopy images. The existing methods also need to be improved in

identifying small-scale SR regions from the cervix images, which will cause difficulty in differentiating the SR area from the acetowhite region. So, these small-scale white regions should also be removed from the cervix images. To overcome this problem, proposed an approach on “*intensity-based threshold method (IBTM)*” to determine the reflection region from the smart colposcopy images using the color space model.

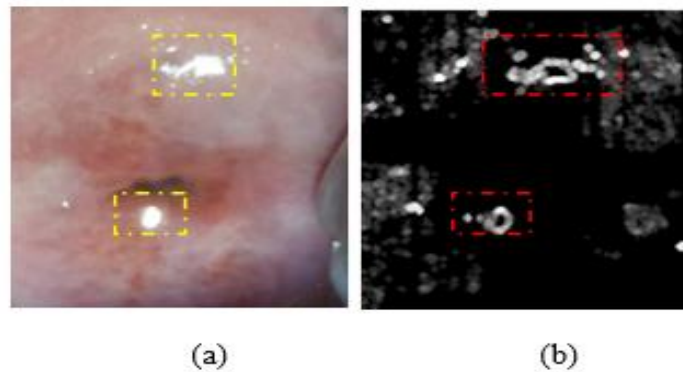


Figure 4.6 Identification of Specular Reflection using Fusion Methods. (a) Original Image with specular reflection (Yellow Maked). (b) Reflection identified using fusion method

4.2. Outline of the Method Proposed

Based on the analysis of the existing method, the color space model plays a key role in identifying SR. The physicians use smart colposcopy images for visual analysis to identify neoplasms. So, applying some computation process should not influence the hue quality and originality of the images. So, identifying a suitable color space is essential in determining the SR from the smart colposcopy images. After identifying suitable color space, the intensity-based threshold method is applied to identify the SR from the smart colposcopy images. The proposed method is compared with the existing methods, such as the adaptive threshold, chromaticity and luminance-based threshold, and fusion methods. The suggested method outperforms the current approach and more accurately detects the reflection on the images. The outline of the proposed method is shown in Figure 4.7

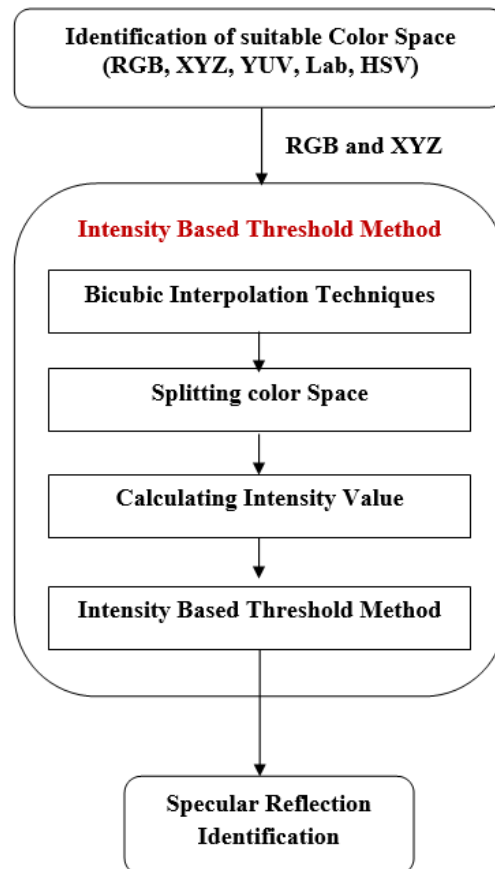


Figure. 4.7 Proposed Method for the Identification of Specular Reflection

4.2.1 Identification of Suitable Color Space for Detection of Specular Reflection

The term “*specular reflection*” (SR) describes how light reflects off the surface of the pictures like a mirror. Identifying the SR in an image can be challenging but can be facilitated by analyzing the color space. Different color spaces provide various advantages for image processing tasks. Based on the literature study, RGB, HSV, Lab, XYZ, and YUV are the most commonly used color spaces for SR recognition. Some color space components typically have luminous properties computed to identify the glare region on the medical images. Let's briefly discuss each color space and its properties in the prediction of SR region.

A) RGB Color Space

It is highly used in digital image processing and medical image analysis. It represents the color by specifying the intensity of “*Red (R), Green (G) and Blue (B)*” primary colors. The degree of intensity value in these color spaces spans from 0 to 255. The value 0 represents the absence of color or the darkest portion, while 255 represents the

images' maximum intensity or brightest portion. It is also represented in decimal terms, ranging from 0.0 to 1.0. The formula to combine three primaries to obtain the complete color image is shown in equation (4.8).

$$RGB = (R, G, B) \quad (4.8)$$

Where:

- R symbolizes the of red, ranging from 0 to 255 or 0.0 to 1.0.
- G symbolizes the of green, ranging from 0 to 255 or 0.0 to 1.0.
- B symbolizes the of blue, ranging from 0 to 255 or 0.0 to 1.0.

The G channel have the properties of low saturation and high intensity [136], which is similar to the reflection region. It is predicted using these properties by applying some computation process. Similarly, the blue channel detects the glare region because it also has the properties of low saturation and high-intensity value.

B) HSV Color Space

It symbolized as “*Hue, saturation, and value*”. The hue channel indicates the color, which extends from 0 to 360 degrees. It forms a color wheel often expressed in degrees ranging from 0 to 360, where 120^0 symbolize the green, and 240^0 symbolize the blue, with the intermediate value representing the different hues. Saturation (S) channels represent the intensity of the color, represented in percentage. If the value of S is 0%, it is represented in a grey potion; if the value is 100%, it means the high-intensity value of the images. Similarly, Value (V) represents the brightness or lightness of the color. The value 0% represents the black, while 100% represents the maximum brightness of the color [137]. The RGB to HSV color transformation is represented below:

The initial step is normalizing the RGB values of the images using the equation (4.9) where R' , G' , and B' are the normalized RGB channels.

$$R' = \frac{R}{255}; G' = \frac{G}{255}; B' = \frac{B}{255} \quad (4.9)$$

The V channel is calculated using the equation (4.10), where *max* represent the maximum value of the normalized RGB channels.

$$V = \max(R', G', B') \quad (4.10)$$

The S channel is calculated using the equation (4.11), where \min indicates the minimum value of the normalized RGB channels.

$$S = \begin{cases} \frac{V - \min(R', G', B')}{V}, & \text{if } V \neq 0 \\ 0, & \text{if } V = 0 \end{cases} \quad (4.11)$$

If V is not equal to 0, the S is computed by taking the distinction between the maximum normalized RGB value V and the minimum of the normalized RGB values $\min(R', G', B')$ and then dividing by V . This normalization is done to account for the intensity of the reflection concerning the overall brightness of the pixel. If V equal to 0, indicating a completely black pixel, then the S is set to 0.

The Hue value of the HSV color space is calculated using equation (4.12)

$$\left. \begin{aligned} \text{If } V = R', \text{ then } H &= \frac{(G' - B')}{(6 * s)} \\ \text{If } V = G', \text{ then } H &= \frac{1}{3} + \frac{(B' - R')}{(6 * s)} \\ \text{If } V = B', \text{ then } H &= \frac{2}{3} + \frac{(R' - G')}{(6 * s)} \end{aligned} \right\} \quad (4.12)$$

If the H value is less than 0, then the H value is represented as $H+1$, and if the value of H is greater than 1, then the H value is defined as $H-1$.

C) XYZ Color Space

It is the standard color space defined by the “*International Commission on Illumination (CIE)*”. It is a device-independent color model representing color based on the human perception of light. Each components indicates the tristimulus values. The spectral power dispersion of light calculates it and corresponds to the amount of stimulation of the three distinct categories of cone cells in the human eyes. The X, Y and Z provide color information with intensity values ranging from 0 to 255. The Y component has luminous properties, which are used to identify the SR region on the image. To convert RGB to XYZ color space, initially, each channel of the RGB is normalized using the equation (4.9). The R'' , G'' , and B'' is the transformation applied to the normalized R, G, B channel using the equation (4.13).

$$\left. \begin{aligned}
 R'' &= \text{if}(R' > 0.04045) \text{then} \left(\frac{R'+0.055^{2.4}}{1.055} \right) \text{else} \left(\frac{R'}{12.92} \right) \\
 G'' &= \text{if}(G' > 0.04045) \text{then} \left(\frac{G'+0.055^{2.4}}{1.055} \right) \text{else} \left(\frac{G'}{12.92} \right) \\
 B'' &= \text{if}(B' > 0.04045) \text{then} \left(\frac{B'+0.055^{2.4}}{1.055} \right) \text{else} \left(\frac{B'}{12.92} \right)
 \end{aligned} \right\} (4.13)$$

The linear RGB values are calculated using the equation (4.14)

$$R_{linear} = R'' * 100; G_{linear} = G'' * 100; B_{linear} = B'' * 100 \quad (4.14)$$

The XYZ values are calculated using the equation (4.15)

$$\left. \begin{aligned}
 X &= R_{linear} * 0.4124564 + G_{linear} * 0.3575761 + B_{linear} * 0.1804375 \\
 Y &= R_{linear} * 0.2126729 + G_{linear} * 0.7151522 + B_{linear} * 0.0721750 \\
 Z &= R_{linear} * 0.0193339 + G_{linear} * 0.1191920 + B_{linear} * 0.950304
 \end{aligned} \right\} (4.15)$$

The equation 4.15 calculates the weighted sum of the linear RGB component R_{linear} , G_{linear} , and B_{linear} with each component multiplied by its corresponding weight to generate the XYZ color images.

D) Lab Color Space

It is also known as CIE LAB, is designed to represent the human perception of the color more accurately than the RGB color models. It consists of three components: L^* for the lightness, a^* indicate the green and red axes and b^* indicate the blue and yellow axes. The L^* component represents the color's lightness, ranging from 0 to 100. The a^* and b^* components represent the color information, where a^* ranges from negative to positive. The lightness or the luminance properties help to recognize the reflection on the images. The RGB color is altered to HSV color space and the white references value of the XYZ is represented in the equation (4.16).

$$X_n=95.047; Y_n=95.047; Z_n=108.883 \quad (4.16)$$

The XYZ values are normalized by dividing them by the reference white values using the equation (4.17).

$$X_{n'} = \frac{X}{X_n}; Y_{n'} = \frac{Y}{Y_n}; Z_{n'} = \frac{Z}{Z_n} \quad (4.17)$$

The nonlinear transformation $f(t)$ is calculated from the normalized XYZ values as represented in the equation (4.18).

$$f(t) = If(t > \left(\frac{6}{29}\right)^3 t \square ent^{\frac{1}{3}} else (t * \left(\frac{29}{6}\right)^{\frac{2}{3}} + \frac{4}{29}) \quad (4.18)$$

The nonlinear transformation of each channel of the XYZ is represented in the equation (4.19).

$$X_{n''} = f(X_{n'}); Y_{n''} = f(Y_{n'}); Z_{n''} = f(Z_{n'}); \quad (4.19)$$

Finally, Lab values are calculated using the equation (4.20) which is used to generate the Lab color images.

$$\left. \begin{aligned} L &= 166 * Y_{n''} - 16, \text{ for } t \square e \text{ lig} \square tened \text{ components} \\ a &= 500 * (X_{n''} - Y_{n''}), \text{ for } t \square e \text{ green} - \text{redopponent colourc omponents} \\ b &= 200 * (Y_{n''} - Z_{n''}), \text{ for } t \square e \text{ blue, yellow opponent colour components} \end{aligned} \right\} (4.20)$$

E. YUV Color Space

It is also known as the $YCbCr$ and is highly used for video encoding, transmission, and display systems. It separates the color information from the brightness of the images. The Y represents the luminance or brightness of the color. It contains the grayscale information, which is responsible for the overall brightness of the images. The value ranges from Y and represents the luminance or brightness of the color. It contains the grayscale information and describes the image's overall brightness. The Y component is usually defined as a range between 0 and 255. The U component represents the chrominance information along the blue-yellow axis. It helps determine the blueness or yellowness of the color. The V component represents the chrominance information along the red-green axis. It represents the color difference between the red component and the luminance. It determines the redness or greenness of the color.

The luma (Y) component is calculated using the equation (4.21), where R' , G' , and B' are the normalized channel of the RGB color space.

$$Y = 0.299 * R' + 0.587 * G' + 0.114 * B' \quad (4.21)$$

The chroma components (U and V) are calculated using the equation (4.22)

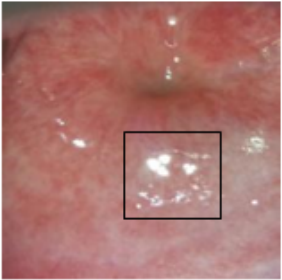
$$U = 0.492 * (B' - Y); \quad V = 0.877 * (R' - Y) \quad (4.22)$$

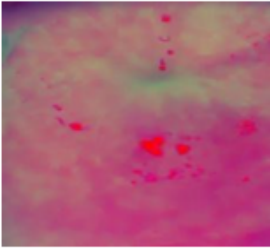

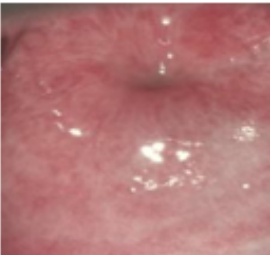
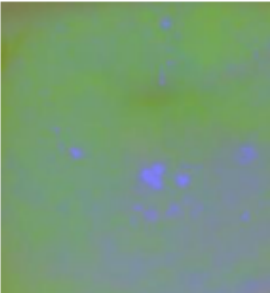
The resulting YUV values are represented as:

- Y (luma) ranging from 0 to 1
- U (chroma-blue) ranging from -0.436 to 0.436
- V (chroma-red) ranging from -0.615 to 0.615

The color transformation applied on the smart colposcopy images to identify the suitable color space for SR, which is discussed in the next sessions. The color transformation is applied to the smart colposcopy images using the above methods. The converted images are analyzed in Table 4.1 in order to choose the appropriate hue space for recognition of SR region on intelligent colposcopy images.

Table 4.1 Analyzing the Transformed Images to Identify the Suitable Color Space for Specular Reflection Detection.

Color space	Color Transformation	Analysis
RGB		<ul style="list-style-type: none"> • The RGB images clearly show the distinction between the dysplasia region and reflection from the other tissue region. • It can help in the identification of SR on the cervical images. • These RGB color images are used by physician for the analysis of the images. • The black box indicates the SR on the cervical images.

Color space	Color Transformation	Analysis
HSV		<ul style="list-style-type: none"> • The RGB images are converted to the HSV color space. • It converts the entire image to a pink appearance, and the SR portion appears as dark pink dots. • The color is more crucial for identifying the cancer region. This color space helps in reflection identification but is difficult during visual analysis by the physicians and grading process.
Lab		<ul style="list-style-type: none"> • The RGB color image is transformed to Lab color space. • Lab color space converts the cervical image into a green appearance, and the blue dot shows the bright pixels on the images. • It blurs the color of the smart colposcopy images, causing difficulty in further analysis.
XYZ		<ul style="list-style-type: none"> • The captured cervical images are transformed to XYZ color space to identify the SR regions. • These images do not affect the color and quality of the cervical pictures and can be further used to analyze the cancer region on the cervical images. • The term "<i>Device-independent</i>" refers to the fact that XYZ color remains unchanged depending on the device.
YUV		<ul style="list-style-type: none"> • The RGB color images is converted to the YUV color space. • Like the Lab color space, the cervical images are converted to a green image with the blue dot representing the reflection region. • The YUV color space blurs the color of the cervical images and causes difficulty during the analysis of cancer identification.

Analyzing all hue space of the image, the RGB and XYZ color spaces are more suitable for identifying SR region. These color spaces do not impact the color quality and originality of the cervical images because the physician uses the color of the images for the analysis. It is observed that the cervical image color is essential for identifying cancer regions and grading the cervical images. So, the proposed approach using IBTM is applied to the RGB and XYZ color space to identify the SR on the images, which is discussed in the next section.

4.2.2 Proposed Approach on Intensity-based Threshold Method for Specular Reflection Identification

Based on the color space analysis conducted above, it is determined that RGB and XYZ are suitable color spaces for identifying SR without altering the color of the images. Subsequently, the threshold method is employed within these color spaces to detect SR in the smart colposcopy images. By applying the threshold method to both the RGB and XYZ color spaces, it identifies the most suitable color space for effectively identifying specular reflections in the smart colposcopy images.

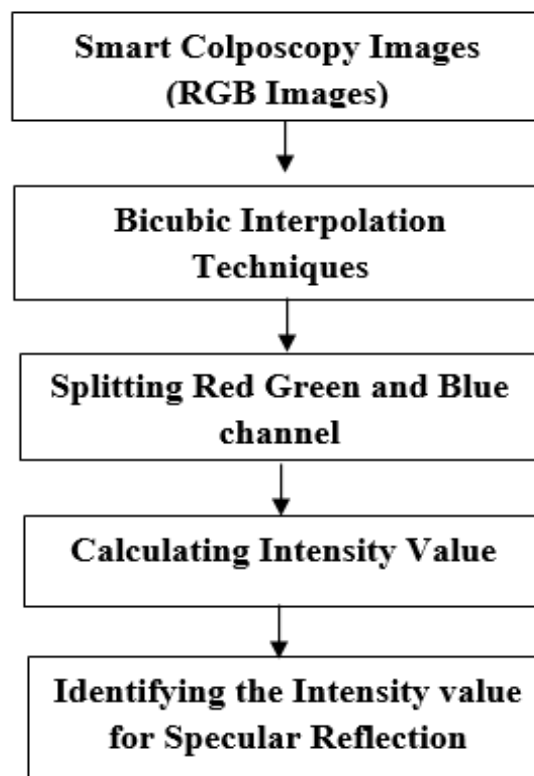


Figure. 4.8 Proposed Methodology SR Identification using RGB color space

Method 1: Identification of SR on using RGB Color Space

Specular reflection (SR) is the bright white spot that appears on the smart colposcopy images covering certain regions of the images. Based on the above literature review, the reflection has the properties of high saturation and intensity, i.e., based on the examination, the reflection has a higher intensity value in the colposcopy image than the other regions of the images. So, in this proposed method, the intensity value is considered to identify the SR area on the images., as indicated in Figure 4.8.

Step: 1Bicubic interpolation Method to Resize the Images (255x255)

Bicubic interpolation is a method used resizes an image based on surrounding pixel values. It involves estimating the values of modified pixels by considering the neighboring pixels in a 2x2 grid. It uses the neighboring pixels to construct a bicubic polynomial interpolation function. This interpolation function is then evaluated at the output position to estimate the pixel value. It is iterated for all the pixel in the final image, resulting in a resized image with smoother transitions. This method is highly used in medical image processing due to its quality of preservation in edges [138]. It calculates the scaling factors for resizing the images in X-axis and Y-axis. At each point, the weight is calculated on the surrounding pixel of the input images using the 2x2 grid size of neighboring pixels. The bicubic interpolation is represented using the equation (4.23).

$$f(x, y) = \sum_{i=0}^3 \sum_{j=0}^3 w(i, x) * w(j, y) * P(i, j) \quad (4.23)$$

where $f(x,y)$ symbolize the interpolated pixel value at the specific position of (x,y) , $w(i,x)$ and $w(j,y)$ represent the weight, which calculates the distinction between the target pixel and the neighboring pixel in the x and y direction, the $p(i,j)$ indicates the pixel value of the neighboring pixel in the 2x2 grids. It reduces the aliasing artifacts that occur during the resizing of images. Its smoother transition between pixels, preserving each fine detail and edges accurately, resulting in the higher grade of the resized images.

Step2: Splitting Each Channel of the RGB Color Space

Each channel of the color space is used to detect the glare region of the digital images because sometimes each channel has a small reflection region even though it does not provide any color information [67]. So, in this proposed method, each channel of the

RGB is used to identify the glare region. So, each channel is split as R, G and B using the equation (4.24).

$$\left. \begin{aligned} \text{Red Channel (R): } R(x, y) &= R(x, y) [0] \\ \text{Green Channel (G): } G(x, y) &= G(x, y) [1] \\ \text{Blue Channel (B): } B(x, y) &= B(x, y) [2] \end{aligned} \right\} (4.24)$$

where [0], [1], [2] denote the indices of the “Red, Green and Blue” channels within the RGB pixel values. It extracts each individual channel of the RGB image and that is used for further process and analysis.

Step 3: Calculate the Intensity Value of Each Channel

The intensity value of each channel is calculated to recognize the average intensity value or the grey scale value of each channel in the RGB images. Very few regions of the images fall in the specular reflection, whereas others are the non-specular reflection. So, calculating the intensity value helps in identifying the average intensity of the non-specular region. The intensity value of each channel calculated using the equation (4.25). The mean level intensity value of the RGB color image is 152. After identification of the average value, the remaining intensity values are manually examined to identify the glare region that falls in the images.

$$\text{Intensity} = \frac{R+G+B}{3} \quad (4.25)$$

Step 4: Identification of Specular Reflection using Threshold Method

The proposed method relies on the intensity value of the cervical images acquired through the smart colposcopy images. The digital images have an intensity value ranging from 0 to 255, in which 0 represents the darker portion and 255 indicates the lighter portion of the images. The average intensity value of the RGB color image is 152. So, the intensity value from 150 to 255 is analyzed manually to identify the reflection region, as shown in the Figure 4.9.

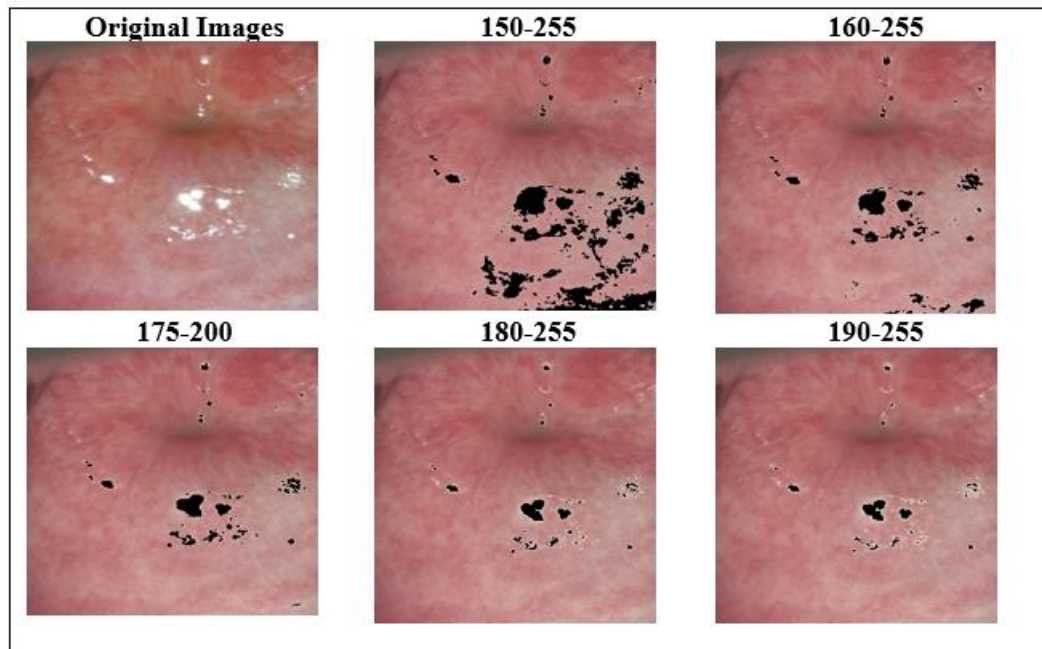


Figure 4.9 Analyzing Each Intensity value of the Images to Identify the SR Region

Algorithm: 4.1

Input: Image Dataset represented as a 2D array "pixel" with size (img_height, img_width)

Output: Specular Reflection Detected Images

For each x **in range** 0 to (img_height - 1):

For each y **in range** 0 to (img_width - 1):

Split channels of the RGB image

$R, G, B = \text{split_channels}(\text{pixel}[y, x])$

Calculate intensity value based on the RGB channels

$\text{intensity} = (R + G + B) / 3$

Set threshold values for the reflection region

if $\text{intensity} \geq 191$ **and** $\text{intensity} \leq 255$:

$\text{pixel}[y, x] = 0$

End

On analysis, the reflection region ranges from 190 to 255 falls in the reflection region and others in the non-reflection areas. The intensity region of the cervical images ranges from 190-255 and is adjusted and set as 0 to mark the SR region on the images. The identification of the SR on the smart colposcopy images using RGB color space is represented in Algorithm 4.1

Method 2: Identification of SR utilizing XYZ Color Space

The image surface exhibits the white bright intensity value characteristic of specular reflection. Here, the XYZ-converted images are used for further processing instead of RGB color space. The proposed methodology for detecting SR region is shown in the Figure. 4.10.

Step 1 Converting RGB to XYZ color space

The smart colposcopy images collected are transformed to XYZ color space using the equation (4.26).

$$\begin{bmatrix} X \\ Y \\ Z \end{bmatrix} = \begin{bmatrix} 0.412453 & 0.357580 & 0.180423 \\ 0.212671 & 0.715160 & 0.072169 \\ 0.019334 & 0.119193 & 0.950277 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (4.26)$$

Step 2: Bicubic Interpolations Method to Resize the Images (255x255).

The images transformed are resized using the bicubic interpolation method by applying the equation (4.23). The images are uniformly reduced to dimensions of 255x255 [138]. This resizing method is recognized for its capacity to maintain high pixel quality in medical images. This standardization not only aids in maintaining consistency but also contributes to reducing computational overhead during the training phase, thereby enhancing efficiency.

Step 3: Splitting X Y and Z Channels from XYZ Color Space

Each channel of the XYZ is used to identify the glare region. So, each channel is split as X, Y and Z using the equation (4.27).

$$\left. \begin{array}{l} X \text{ Channel (X): } X(x, y) = X(x, y) [0] \\ Y \text{ Channel (Y): } Y(x, y) = Y(x, y) [1] \\ Z \text{ Channel (Z): } Z(x, y) = Z(x, y) [2] \end{array} \right\} \quad (4.27)$$

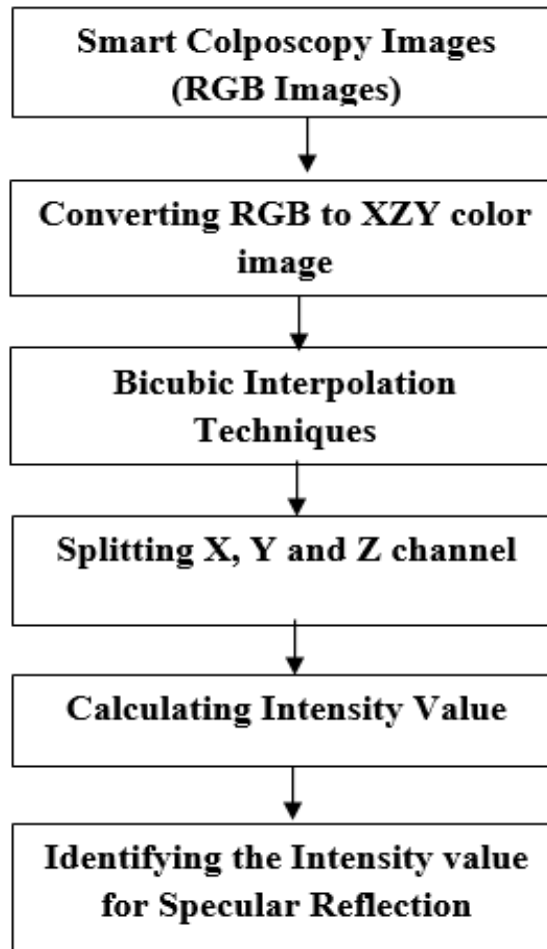


Figure.4.10 Proposed Methodology for the Detection of Specular Reflection using XYZ color space

where [0], [1], [2] denote the idiocies of the X, Y and Z channels within the XYZ pixel values. It extracts each individual channel of the XYZ image, and that is used for further process and analysis.

Step 4: Calculating the Intensity Value of the Images

The intensity value of every channel is calculated to compute the average intensity range in the XYZ images. The value of all channel is calculated using the equation (4.28). The average intensity value of the XYZ color image falls in the pixel value of 162.

$$Intensity = \frac{X+Y+Z}{3} \quad (4.28)$$

Each channels denote the intensity values of the X channel, Y channel, and Z channels, respectively, at a given pixel location in the XYZ image. The resulting intensity value

represents the overall brightness or luminance of the pixel, enabling a grayscale representation of the color image.

Step 5: Identification of Specular Reflection Using Threshold Method.

The prediction of glare regions in cervical images is based on the pixel intensity values, considering their high-intensity properties. In digital images, pixel intensity values typically range from 0-255, in which zero indicates the pixel with dark shade and 255 indicate the bright shade. Manual analysis of each intensity value is conducted to recognize glare regions, as illustrated in Figure 4.11. The SR pixels are characterized by intensity values falling within the range of 201-255, while non- SR regions correspond to intensity values in the range of 0-200. The labeling of SR and non-SR regions is achieved through the application of a binary mask outlined in Algorithm 4.2.

<p>Algorithm 4.2:</p> <p>Input: Image Dataset represented as a 2D array "pixel" with size (img_height, img_width)</p> <p>For each x in range 0 to (img_height - 1)</p> <p>For each y in range 0 to (img_width - 1)</p> <p> Convert the RGB color values of the pixel at position (y, x) to XYZ color space. Set current_pixel_intensity = value of "pixel" at position (y, x) in the XYZ color space</p> <p> Set current_pixel = value of "pixel" at position (y, x)</p> <p>If current_pixel \geq 201</p> <p> Set the value of "pixel" at position (y, x) to 1</p> <p>Else if current_pixel \leq 200</p> <p> Set the value of "pixel" at position (y, x) to 0</p> <p>End</p>
--

4.3. Qualitative Analysis

It consists of 4000 images, grouped as "Type 1, Type 2 and Type 3" based on the acetowhite region that depicts on the layer of the images, randomly selected 250 images from type 1, 250 images from the variety and 500 images from type 3. So, in this analysis, 1000 images are selected and trained using the GPU processor with the 12GB RAM provided by the Google Collaboratory. This session discusses about the comparison analysis to identify the suitable method that outperforms on smart colposcopy images in identification of SR region.

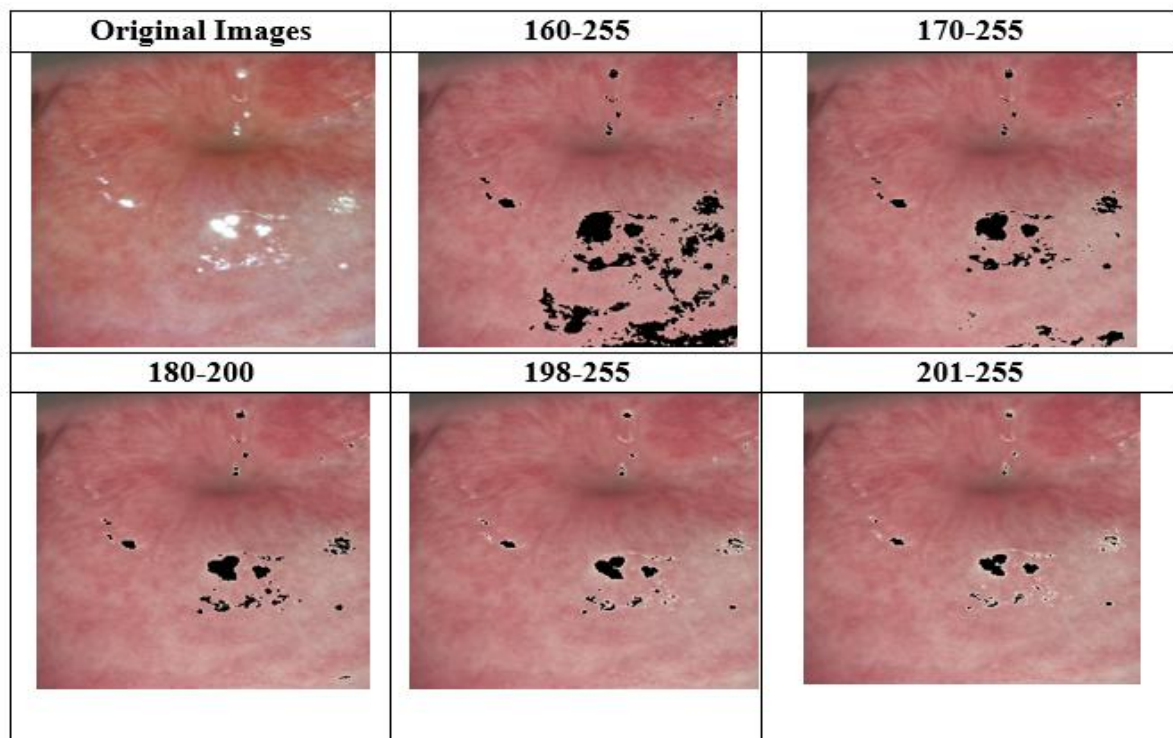


Figure 4.11 Specular Reflection Identification using Intensity based Threshold Method using XYZ color space

4.3.1 Comparison Analysis

The proposed and the conventional methods are compared to identify a suitable model for SR identification in the images. On analysis, the adaptive threshold method, leads to the damage of the pixels, and some of the non- SR regions are removed from the colposcopy images by using the HSV color space, as shown in Figure 4.12 (d). The SR has the properties of large-intensity regions and small-intensity regions. In the chrominance luminance-based threshold method, the SR regions with the large-scale intensity value are identified, and small reflections are not recognized using this method. Along with the reflection identification, white tissue regions of the cervix images are also recognized as glare regions, as shown in Figure 4.12(e). The fusion method combines three color channels with a similar property of the specular highlight used in detecting the SR region. This method identifies the reflection on smart colposcopy images, which are unclear and appear blurred, as shown in Figure 4.12 (f). It causes difficulty in identifying the correct highlighted area and also causes problems while removing the SR from the cervix images.

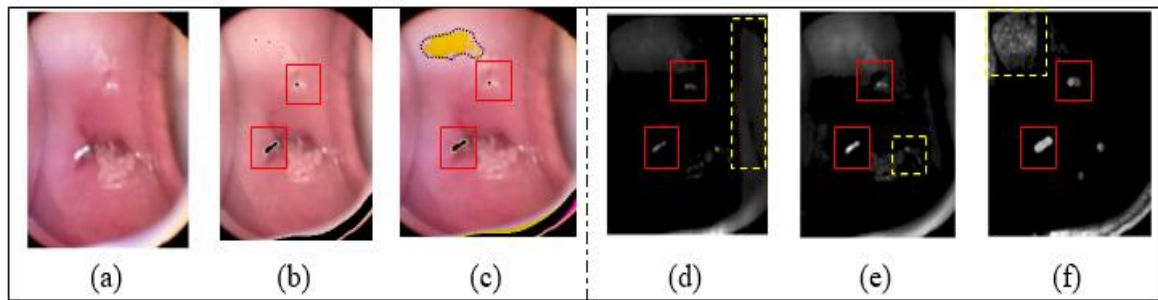


Figure 4.12 Comparison of Performance Analysis of the Proposed and Existing Method to Identify the SR on the Images




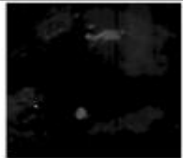
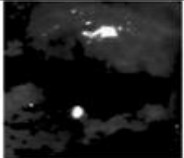
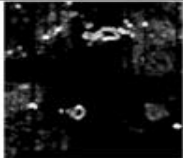



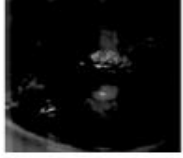
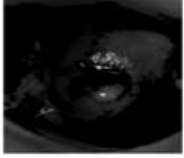
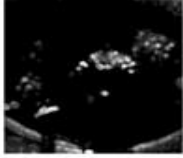





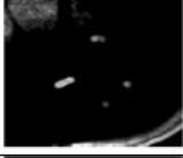
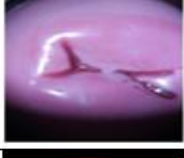


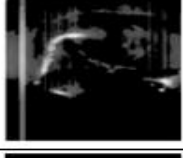
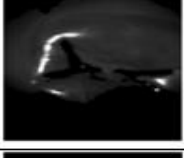
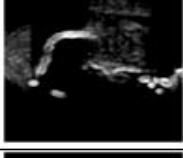


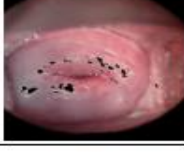
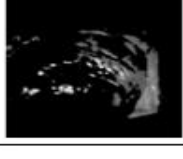
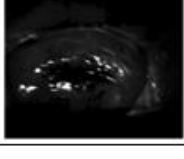

On qualitative evaluation of each color space, RGB and XYZ do not influence the hue of the images. The above conventional method aids in the identification process, but the color transformation to identify the reflection region affects the originality of the images. The method proposed utilizes the intensity of the colposcopy images, leveraging the higher intensity properties of the reflection region. So, to identify the SR on smart colposcopy images, proposed an approach on IBTM on RGB and XYZ color images. The proposed IBTM on RGB color image identifies the reflection region without affecting the non-SR region. It also identifies the reflection with the higher intensity value and low-intensity value. However, this proposed method on RGB color images affects the pixel value, forming yellow patches on the images, as illustrated in Figure 4.12(c). It happens due to a change in the intensity value of the images. So, the method proposed is applied on color spaces of XYZ to recognize the SR region on the images. The proposed method on XYZ color space identifies the reflection with the higher intensity value and low-intensity value. In this method, there is no formation of yellow patch on the smart colposcopy because of its device independent properties as shown in Figure 4.12 (b). Based on the analysis, XYZ color space with a pixel range from 200-255 accurately identifies the reflection portion without affecting the image quality. The proposed approach recognizes the reflection area from the smart colposcopy images and outperforms the existing methods based on quality evaluation. The comparison of the results is shown in Table 4.2.

4.3.2 Recognizing Specular Reflection Without Interfering with the Acetowhite Region

The acetic acid is applied during the examination process, dehydrating the cancer cell and appearing as the acetowhite portion on the captured images. The major challenge faced during the identification of SR is the existing method's failure to differentiate the acetowhite region because of its similar appearance. However, the proposed method (IRBM

on XYZ color images) identifies the reflection area without influencing the SR pixels, as shown in Figure 4.13.

Table 4.2 Comparison of the Existing and the Proposed Method for the Detection of Glare Region

Original Images	Proposed Method on RGB Color Images	Proposed Method on XYZ Color Images	Adaptive Threshold Method	Chrominance and Luminance Based Threshold method	Fusion Method
					
					
					
					
					

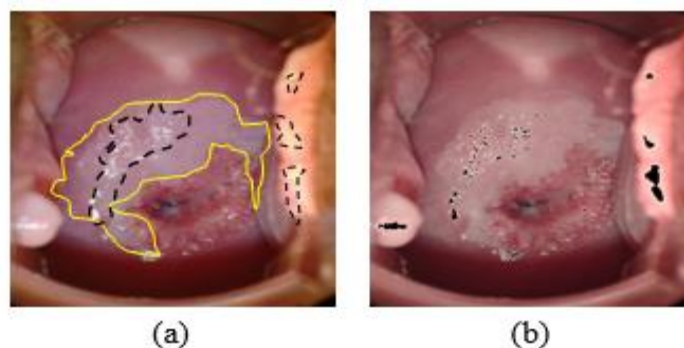





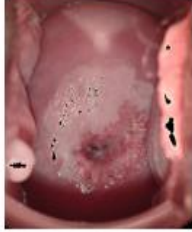

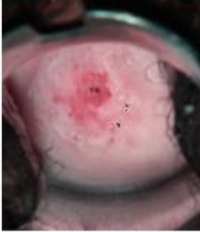






Figure 4.13 SR detection on the Images without Affecting the Acetowhite Region. (a) Original image with specular reflection (Marked with Black dotted lines) and Acetowhite Region (Marked with Yellow lines). (b) Smart Colposcopy images with detected specular reflection (Black Region)

The acetowhite region is the neoplasm that appears on the smart colposcopy images. They differ on each stage of cancer. In type 1 (i.e., stage 1 of cervical cancer), the acetowhite region appears significantly less in the images. Similarly, in type 2, the acetowhite region appears slightly higher in the second stage of the cancer, and in type 3, the acetowhite region appears in almost all the images. So, the execution of the method is checked on all the types of images, as indicated in Table 4.3. On analysis, the techniques proposed identify the SR on the image without affecting the acetowhite region at three types of smart colposcopy images.

Table 4.3 Recognizing SR Without Interfering with the Acetowhite Region

Cervical Cancer Grading	Original Images	Specular Reflection Images Detected	Original Images	Specular Reflection Images Detected
Type 1				
Type 2				
Type 3				

4.3.3 Recognizing Specular Reflection without Interfering with the White Discharge

Like the acetowhite region, the other challenge faced during the SR detection process is the white discharge. Identifying and differentiating the white discharge from the specular reflection is challenging due to the bright or white area on the smart colposcopy images. White discharge is the vaginal discharge commonly seen in women; mainly, these are captured during the screening procedure.

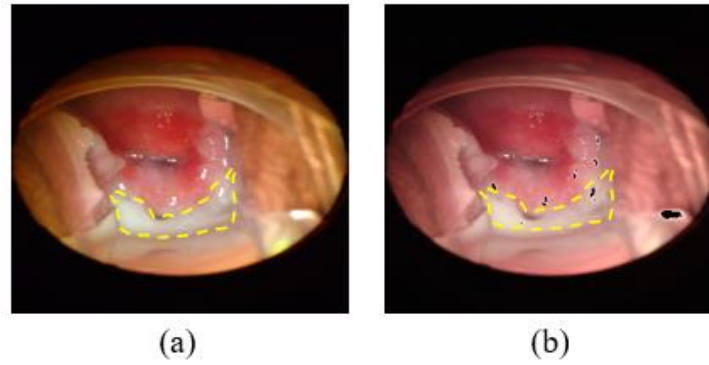


Figure. 4.14 SR Detection on the Images Without Affecting the White Discharge. (a) Original image with the white discharge (Marked Yellow dotted lines) (b) Detected specular reflection (Black marked) without affecting the white discharge (Marked Yellow dotted lines)

On analysis, the proposed method identifies the reflections on the smart colposcopy images without influencing the white discharge on the images, as represented in the Figure.4.14. This white discharge on each cancer grade is also analyzed, as represented in Table 4.4.

Table.4.4 Recognizing Specular Reflection without Interfering with the White Discharge

Smart Colposcopy Types	Original Image	SR Detected Images	Original Images	SR Detected Images
Type 1				
Type 2				
Type 3				

4.3.4 Applying Proposed Method on Smart Colposcopy Image Without Specular Reflection

On analysis, some of the images are not affected by the SR as represented in the Figure 4.15(a). On analysis, the proposed method does not affect the non-SR images, as indicated in Figure 4.15(b).

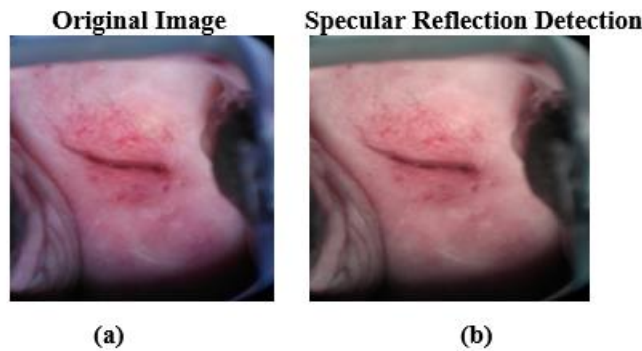


Figure.4.15 Applying Proposed Method on Non-Glare Images. (a) Original image with the white discharge without reflection region on the images (b) No glare region is detected.

4.4 Quantitative Evaluation

For the quantitative analysis, the detection of SR is manually marked, which is taken as the ground truth images for further analysis. To evaluate the quantitative performance accuracy, specificity, sensitivity and precision were calculated with the ground truth and SR detected images. The metric used to assess the classification model's overall correctness is called accuracy. It represents the proportion of accurately recognized out of the total quantity of occurrences. Equation (4.29) uses the count of accurately detected reflections divided by the total count of reflection pixels to determine the accuracy of SR detection on smart colposcopy images.

$$Accuracy = \frac{Total\ number\ of\ correctly\ identified\ Reflection\ Pixel}{Total\ Number\ of\ Reflection\ Pixel} \quad (4.29)$$

Precision is the metric that calculates the percentage of all SR to the number of successfully identified SR from the cervix images as in the equation 4.30. The accuracy of the model in identifying accurately identified SR patches is measured by the precision.

$$Precision = \frac{True\ Positive}{True\ Positive + False\ Positive} \quad (4.30)$$

Where:

- “True Positive” is the count of SR regions correctly identified as such.
- “False Positive” is the count of non- SR regions incorrectly classified as SR regions.

The percentage of true positive cases that the model correctly detects is measured by sensitivity. It is calculated using the ratio of accurately identified SR to the total count of SR pixels from the cervix images, as in equation 4.31.

$$Sensitivity = \frac{TruePositive}{TruePositive+FalseNegative} \quad (4.31)$$

Where:

- True Positive indicates the count of SR pixels correctly identified by the model.
- False Negative indicates the count of SR pixels incorrectly classified as non- SR or missed by the model.

The percentage of real negative cases that the techniques accurately identify is known as specificity. As indicated by the equation (4.32), it determines the ratio of true negatives to the total of true negatives and false positives.

$$Specificity = \frac{TrueNegative}{TrueNegative+FalsePositive} \quad (4.32)$$

Where:

- “True Negative” indicates the number of non- SR region pixels that are correctly identified as such by the model.
- “False Positive” indicates the number of non- SR region pixels incorrectly classified as SR or false positives.

These metrics calculate the SR identification using the proposed method and the other state-of-the-art method.

Table 4.5 Quantitative Evaluation of the Proposed Method and the Existing Method

Methods	Accuracy (%)	Specificity (%)	Sensitivity (%)	Precision (%)
Proposed Method on XYZ color images	89.79	90.38	88.79	83.49
Proposed Method on RGB color images	87.26%	88.24	87.23	77.52
Adaptive Threshold Method	84.03%	83.14	82.74	75.36
Chrominance and Luminance based Threshold Method	82.39%	80.02	81.72	72.35
Fusion method	74.78%	61.35	60.35	72.36

Based on the comparison analysis, the proposed IBTM method on XYZ color space images identifies the SR on the images with an accuracy of 89.79%. It outperforms the existing method provides higher accuracy in detecting SR, as shown in Table 4.5. An image processing expert graded the detection of SR for the proposed and conventional methods. The proposed XYZ method gives the correct detection of SR from each of the three groups of cervix images with a higher image count in all categories of cervix image, as shown in Table 4.6.


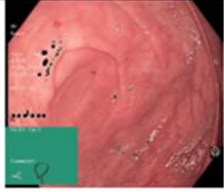

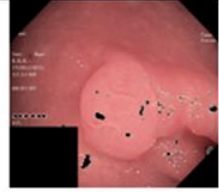

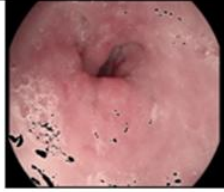






Table 4.6. Quantitative Examination

Methodology	CIN-1 (250 Images)	CIN-2 (250 Images)	CIN-3 (500 Images)
Adaptive Threshold Method	170	85	251
Chrominance and Luminance based Threshold Method	148	154	369
Fusion method	94	96	116
Proposed method on RGB color images	222	232	473
Proposed method on XYZ color images	236	243	495

4.5. Implementation of Specular Reflection Detection on Other Digital Medical Images

The proposed method is not limited to smart colposcopy images, it is applicable on the other digital medical images. Most medical photos acquired through the digital device facing are the SR problem. The proposed method is implemented to the endoscopy [140], digital colposcopy [141], and colonoscopy [139] to check the performance analysis of the SR region. Endoscopy is the device used to examine the body's interior. It consists of a flexible tube with a camera at the end. The endoscopy images are also affected by the glare region. Similarly, colonoscopy is used to examine the colon and rectum region of the human body. It is a screening that captures the colon region for visualization to diagnose the initial stage of diseases. The other is the digital colposcopy, similar to the smart colposcopy used to screen cervical images. These are some of the digital medical images that are affected by SR. It is applied to these images to check the performance of the method proposed, as shown in Table 4.7. It shows that the SR of the proposed method is wider than the smart colposcopy images. It is suitable for the other medical pictures acquired through digital device.

Table 4.7. Implement the Proposed Method utilizing XYZ for Recognition of SR on the Other Medical Images.

Dataset Name/ Image Names	Original Image	Specular Reflection Detected	Original Images	Specular Reflection Detected
The Hyper Kvasir Dataset – Colonoscopy Images				
Esophageal Endoscopy Images – Kaggle				
Colposcopy Image – WHO Dataset				

4.6. Summary

The chapter comprehensively analyzed the color space to identify the suitable color space for identifying the SR on the images. From the analysis, the RGB and XYZ methods were deemed ideal for identification because the screening procedure was based on the naked eye. So, the color should retain its originality when analyzing the images. The intensity-based threshold method was applied to the images to identify the glare region. The SR detection on different color spaces was used for the comparison analysis. On comparison analysis, the proposed approach on IBTM employed on RGB and XYZ methods recognized the SR on the images. The qualitative evaluation of the proposed IBTM approach applied to XYZ recognition indicated highly accurate SR detection. The color of the smart colposcopy images was more important, but the proposed RGB failed in color appearance during the reflection process. The proposed XYZ method identified the reflection region without affecting the image's acetowhite and white discharge region. Similarly, the proposed method was not limited to smart colposcopy; the performance of the proposed method was extended to identifying the glare region on other medical images like digital colposcopy, endoscopy, and colonoscopy images.