Comparative study of Structural Similarity Index (SSIM) by using different edge detection approaches on live video frames for different color models

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Abstract— **Evaluation the quality of the video frame is a complex and hard process since human's opinion is affected by physical and psychological parameters. Various procedures are proposed for evaluating the quality of the video frame. Video frame quality assessment plays a vital role in the field of video processing. Structural Similarity Index (SSIM) has become a standard among image quality metrics. Structural Similarity Index is a framework for quality evaluation based on the degradation of structural information of video frame. Structural Similarity Index is used to assess the similarity between the reference video frame and the processed video frame. Structural Similarity Index is easy and well linked with subject evaluation. Measure of structural similarity index is able to provide a good approximation to perceived image quality. This procedure evaluates the visual impact of changes in luminance, contrast and structure in an image. In this paper SSIM values are calculated and compared for live video frames by applying different edge detection operators for different color models to assess the quality of the frames. Experimental results comparisons demonstrate the effectiveness of the proposed method.**

Keywords—Color Models; Edge Detection; Edge detection operators; SSIM

I. INTRODUCTION

Edges are important local intensity changes in the image and are important features to analyze an image. They are important hints to split region within an object or to identify changes in illumination or color. They are an important feature in the early vision stages in the human eye. Edge detection identifies sudden changes in an image. Primary goal is to extract information about the two-dimensional projection of a 3D scene. Secondary goal is Image segmentation, region separation, objects description and recognition etc.

Edge Point is one in an image with coordinates [i, j] at the location of a significant local intensity change in the image. Edge fragment is a small line segment about the size of a pixel, or as a point with an orientation attributes. The term edge is commonly used either for edge points or edge fragments. Edge detector is algorithm that produces a set of edges from an image. Some edge detectors can also produce a direction that is the predominant tangent direction of the arc that passes through the pixel [1]. Contour is list of edges of the mathematical curve that models the list of edges. Edge linking is a process of forming an ordered list of edges from a un ordered list. Edge following is process of searching the edge image to determine line. Origins of edges are 1.Surface normal discontinuity 2.Depth discontinuity 3. Surface color discontinuity 4.Illumination discontinuity. Using Edge detection procedure major features like corners, lines, and curves can be taken out from the edges of an image. These features are used by algorithms like recognition. The ideal edge detector should discover all real edges by ignoring noise. The detected edges should be as close as possible to the accurate edges. The edge detector must return one point for each true edge point. Cues of edge detection are differences in color, intensity, or texture across the boundary and continuity and closure.

II. DIFFERENT COLOR MODELS

A color model is a method used for creating a full range of colours from primary colors. There are two types of colour models. 1. Additive color model. 2. Subtractive color model. Additive color model uses light to display color. A subtractive color model uses printing inks. A color model describes how colors can be represented as set of values of numbers, typically as three or four values. Color space provides a rational method to specify order, manipulate and effectively display the object colors. Therefore the selected color model should be well suited to deal the problem's statement and solution.

A. The RGB Model

The RGB color model is an additive color model in which primary colors Red, Green and Blue are added together in different ways to reproduce a broad array of colors. The name of the model comes from the initials of the three additive primary colors, Red, Green and Blue. In this model, an image consists of three independent image planes Red, Green and Blue stating a particular color is by indicating the amount of each of the primary components present. Fig.1 shows the geometry of the RGB color model for specifying colors using a Cartesian coordinate system. Red, green, and blue can be pooled in a variety of proportions to get any color in the visible spectrum [1]. Red, Green and Blue can range from 0 to 100 percent of full intensity. Each intensity value is on a scale

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of 0 to 255.In hexadecimal intensity value ranges from 00 to FF.

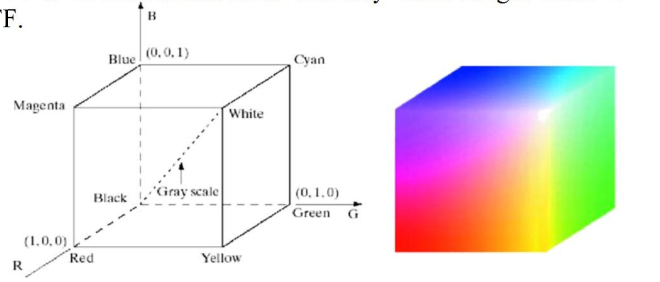


Fig. 1. The RGB color cube. The grey scale spectrum lies on the line joining the black and white vertices.

B. *YUV Color Model*

The YUV color space is derived from the RGB color model. It consists of the luminance(Y) and two color difference (U,V) components. The luminance can be calculated as the weighted sum of the Red, Green and Blue components [2].The chrominance components are produced by subtracting luminance from Blue and Red .YUV color model generally used as part of a color image pipeline. The YUV model describes a color space in terms of one luma (Y') component and two chrominance (UV) components. Y' represents luma component i.e brightness and U and V represents the chrominance i.e. color components. Luminance is denoted by Y and luma by Y′. The symbol (') indicates gamma compression with "luminance" which is perceptual brightness, while "luma" is electronic brightness [3]. Y component ranges from 0 to 1 or 0 to 255 in digital formats, while U and V components ranges from -0.5 to 0.5 or -128 to 127 in signed form or 0 to 255 in unsigned form.

Conversion between RGB – YUV

$$R = Y + 1.4075 * (V - 128) \qquad (1)$$

$$G = Y - 0.3455 * (U - 128) - (0.7169 * (V - 128) \qquad (2)$$

$$B = Y + 1.7790 * (U - 128) \qquad (3)$$

$$Y = R * 0.2990 + G * 0.5870 + B * 0.1140 \qquad (4)$$

$$U = -0.14713 * R - 0.28886 * G + 0.436 * B \qquad (5)$$

$$V = 0.615 * R - 0.51499 * G - 0.10001 * B \qquad (6)$$

C. *YCbCr Color Model*

The YCbCr color model is extensively used for digital video. In this model luminance information is stored as a single component (Y) and chrominance information is stored as two color-difference components (Cb and Cr). Cb component corresponds to the difference between the blue component and a reference value and Cr component corresponds the difference between the red component and a reference value [4]. YCbCr data can be double precision. The data range for Y component is [16, 235] and the range for Cb and Cr components is [16, 240].

$$Y = 0.299R + 0.587G + 0.114B \qquad (7)$$

$$Cb = 128 - 0.168736R - 0.331264G + 0.5B \qquad (8)$$

$$Cr = 128 + 0.5R - 0.418688G - 0.081312B \qquad (9)$$

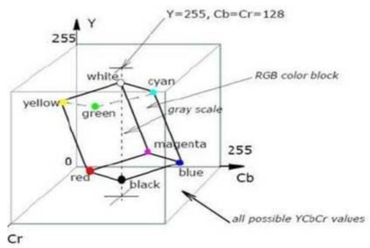


Fig. 2. YCbCr and YUV color models[5],[6]

D. *CIE XYZ Color Model*

The XYZ color space is an international standard developed by the Commission Internationale de I Eclairage (CIE). This model is based on three hypothetical primaries, XYZ and all visible colors can be represented by using only positive values of X,Y,Z. The CIE XYZ primaries are theoretical because they do not conform to real light wave lengths. The Y primary is deliberately defined to match closely to luminance, while X and Z primaries give color information. The main advantage of the CIE XYZ color model is that this model is completely device independent. The position of the block of the RGB representable colors in the XYZ space is shown in Fig.3

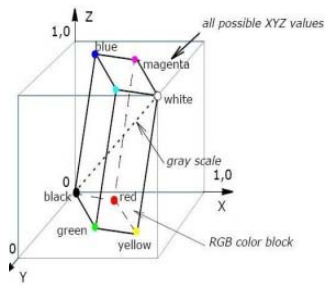


Fig. 3. RGB colors Cube in the XYZ color space [5]

Conversion between RGB and XYZ color space

$$X = 0.4124 * R' + 0.3575 * G' + 0.1804 * B' \qquad (10)$$

$$Y = 0.2126 * R' + 0.7151 * G' + 0.07216 * B' \qquad (11)$$

$$Z = 0.0193 * R' + 0.1191 * G' + 0.9502 * B' \qquad (12)$$

$$R' = 3.2404 * X - 1.5371 * Y - 0.4985 * Z \qquad (13)$$

$$G' = -0.9692 * X + 1.8759 * Y + 0.0415 * Z \qquad (14)$$

$$B' = 0.0556 * X - 0.2040 * Y + 1.0573 * Z \qquad (15)$$

III. EDGE DETECTION OPERATORS

A. *Laplacian Operator*

Laplacian Operator is a derivative operator which is used to find edges in an image. The major difference between Laplacian and other operators like Sobel, Prewitt and Robert is that these all are first order derivative masks but Laplacian is a second order derivative mask [7]. In Laplacian mask there are two types. 1. Positive Laplacian operator 2. Negative Laplacian operator. Another difference between Laplacian operator and other operators is that unlike other operators Laplacian operator didn't take out edges in any particular direction but it take out edges as Inward Edges and Outward edges.

1) Positive Laplacian Operator

Positive Laplacian mask contains center element as negative and corner elements as zero as shown in Fig. 4. Positive Laplacian mask is used to take out outward edges in an image.

2) Negative Laplacian Operator

Negative Laplacian mask contains center element as positive value and all the elements in the corner as zero and rest of all the elements in the mask as -1 as shown in Fig. 4.

0	1	0
1	- 4	1
0	1	0

Fig. 4. Positive Laplacian

0	-1	0
-1	4	-1
0	-1	0

Fig.4. Negative Laplacian

B. Sobel operator

The operator consists of a pair of 3 X 3 convolution kernels. The Fig.5 represents 3 X 3 mask along x-axis and 3 X 3 mask along y-axis. Kernels are designed to react to edges running vertically and horizontally relative to the pixel grid. Kernels can be applied individually to input image to produce separate measurements of the gradient component in each orientation. Kernels can be combined together to find absolute magnitude of the gradient at each point and the orientation of that gradient [8].

-1	0	1
-2	0	2
-1	0	1

1	2	1
0	0	0
-1	-2	-1

Fig. 5. 3 X 3 mask along X-axis 3 X 3 mask along Y-axis

C. Robert operator

Robert operator is a first-order operator, which uses a partial differential operator to find the edge. It uses the approximation between the two adjacent pixels of the diagonal direction of the gradient amplitude to detect edge[8]. In 2x2 diagonal derivative, the two convolution kernels, Gx = [1 0; 0 −1] and Gy = [0 1; −1 0] are shown in Fig.7

Roberts's operator is defined as

$$G(x,y) = \{[\sqrt{f(x,y)} - \sqrt{f(x+1,y+1)}\,]^2 + [\sqrt{f(x+1,y)} - \sqrt{f(x,y+1)}\,]^2\}^{\frac{1}{2}} \tag{16}$$

Gradient size of Roberts operator represents the strength of the edge and direction of the gradient. The operator edge has higher positioning accuracy, but it is easy to lose a part of the edge. The operator with a steep low-noise image corresponds best.

1	0
0	-1

0	1
-1	0

Fig. 6. Robert Mask

D. Prewitt operator

The Prewitt operator is edge model operator. This operator is made from the ideal edge sub-image composition. Detect the image using this edge model one by one and acquire the highest value of the model operator that is most similar to the detected region as the output of the operator [9]. Prewitt and Sobel operator uses the similar differential and filtering process, but the template does not use the same image. This gradient based edge detector is estimated in the 3x3 neighborhood for 8 directions [8]. All the eight convolution masks are calculated. Then convolution mask which is having largest module is chosen. The convolution masks of the Prewitt detector are shown in Fig.7.

1	1	1
0	0	0
-1	-1	-1

1	1	1
0	0	0
-1	-1	-1

Fig. 7. Prewitt Mask

IV. STRUCTURAL SIMILARITY INDEX(SSIM)

The Structural Similarity (SSIM) index is a method for evaluating the perceived quality of digital images and videos. An early variant was developed in the Laboratory for Image and Video Engineering (LIVE) at the University of Texas at Austin and the full algorithm was developed jointly with the Laboratory for Computational Vision (LCV) at New York University. Structural Similarity is used for measuring the similarity between two images [10]. The Structural Similarity index is a measurement or prediction of image quality based distortion-free image as reference. Peak signal-to-noise ratio (PSNR) and mean squared error (MSE) have proven to be inconsistent with human visual perception. Mean squared error (MSE) and Peak signal-to-noise ratio (PSNR) estimates absolute errors, where as SSIM is a perception-based model that considers image degradation as perceived change in structural information by incorporating important perceptual phenomena, including both luminances masking and contrast masking. Structural information is the design that the pixels have strong inter-dependencies when they are spatially close. These dependencies carry significant information about the structure of the objects in the visual scene. Luminance masking is a phenomenon whereby image distortions tend to be less visible in bright regions, where as contrast masking is a phenomenon whereby distortions become less visible where there is texture in the image. The SSIM index is calculated on various windows of a frame. The measure between two windows and of common size N×N is

$$SSIM(x,y) = \frac{(2\mu_x\mu_y + c_1)(2\sigma_{xy} + c_2)}{\left(\mu^2{}_x + \mu^2{}_y + c_1\right)(\sigma^2{}_x + \sigma^2{}_y + c_2)} \quad (17)$$

μ_x the average of x
μ_y the average of y
σ_x^2 the variance of x
σ_y^2 the variance of y
σ_{xy} the covariance of x and y
$c_1=(k_1L)^2$ & $c_2=(k_2L)^2$ two variables to stabilize the division with weak denominator
L the dynamic range of the pixel-values
$K_1=0.01$ and $k_2 = 0.03$ by default

Symmetry condition of SSIM index is defined as

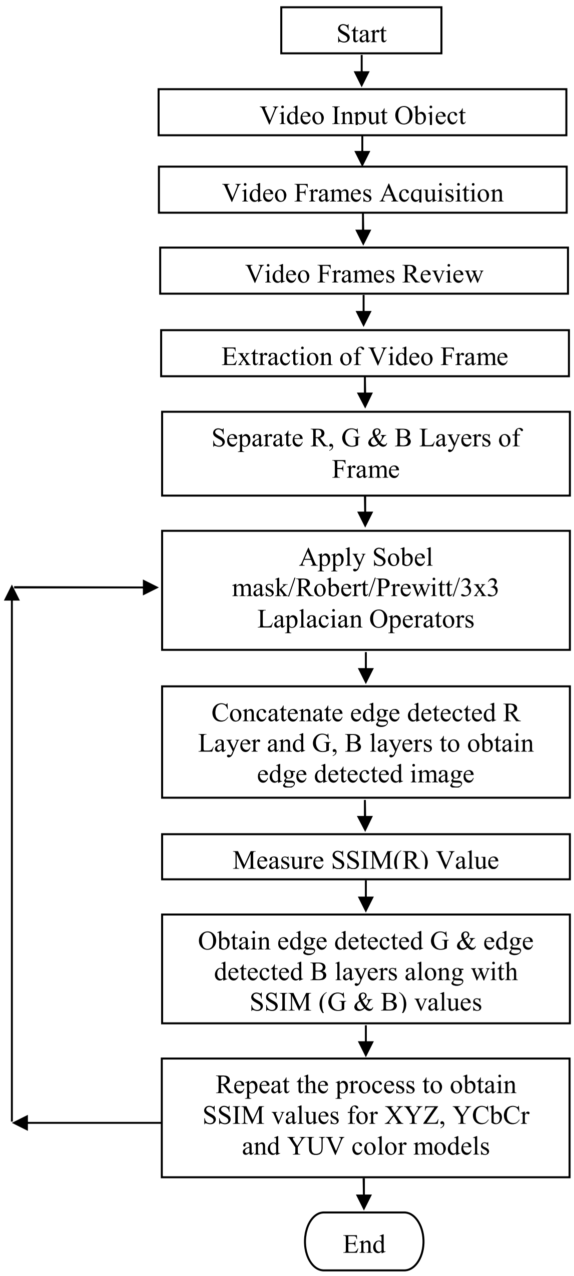
SSIM(x, y) =SSIM(y, x). In order to assess the image quality, this formula is generally applied on luma, color values or chromatic values. The resultant SSIM index is a decimal value between 0 and 1[1].

V. PROPOSED ALGORITHM

Edge detection & calculation of SSIM value based on different color models & edge detection operators for live video frames can be explained by the following steps.

Step 1: Constructing a video input object
Step 2: Select the source to use for video frames acquisition
Step 3: View the properties for the selected video source object.
Step 4: Preview the stream of video frames
Step 5: Acquire and display a single video frame
Step 6: Video frame is sub divided into R, G and B layers.
Step 7: A Laplacian mask of size 3 X 3 is convolved with R layer of Video Frame to detect the edges to obtain edge detected R layer.
Step 8: Edge detected R layer and G, B layers of video frame are concatenated to obtain edge detected frame.
Step 9: The SSIM(R) parameter is measured. The same process is repeated to obtain the edge detected G layer and edge detected B layer along with SSIM (G & B) parameter
Step 10: The average value of SSIM(R), SSIM (G) and SSIM (B) gives SSIM value of RGB frame.
Step 11: Repeat steps 6 to 10 for Sobel, Prewitt's and Robert's Operators
Step 12: Repeat steps 6 to 11 for XYZ, YCbCr and YUV color models.

VI. FLOW CHART



VII. EXPERIMENTAL RESULTS

The proposed algorithm has been applied to Live Video frames for different color models by applying Sobel, Robert, Prewitt's and Laplacian operators. The edge detected video frames are obtained for RGB, XYZ, YCbCr and YUV color models. The detected edges are more exact based on the XYZ color model and are detected effectively when compared with RGB, YCbCr and YUV color models. Mean SSIM values are obtained and shown in Table.1. Based on the SSIM metrics, XYZ color model is having high similarity index which indicates low data loss during transformation. The video frames obtained through YUV color model are losing structural information and highly distorted when compared with the RGB, XYZ, YCbCr color models. Only a set of sample video frames are presented here for display from among 240 video frames.

TABLE.1.MEAN SSIM VALUES FOR VIDEO FRAMES FOR DIFFERENT OPERATORS

VIDEO FRAME NO	COLOR MODEL	Mean SSIM Values			
		SOBEL	***ROBERT***	***PREWITTS***	***LAPLACIAN***
FRAME 1	**RGB**	*0.1271*	*0.1303*	*0.1323*	*0.1250*
	XYZ	*0.9958*	*0.9937*	*0.9967*	*0.9966*
	YCbCr	*0.0232*	*0.0916*	*0.0906*	*0.0912*
	YUV	*0.0410*	*0.0967*	*0.1094*	*0.1079*
FRAME 2	**RGB**	*0.1113*	*0.1139*	*0.1123*	*0.1106*
	XYZ	*0.9961*	*0.9941*	*0.9969*	*0.9969*
	YCbCr	*0.0503*	*0.0936*	*0.0929*	*0.0934*
	YUV	*0.0345*	*0.0799*	*0.0921*	*0.0883*
FRAME 3	**RGB**	*0.1144*	*0.1171*	*0.1147*	*0.1138*
	XYZ	*0.9958*	*0.9937*	*0.9967*	*0.9967*
	YCbCr	*0.0694*	*0.0956*	*0.0953*	*0.0955*
	YUV	*0.0393*	*0.0865*	*0.1009*	*0.0965*
FRAME 4	**RGB**	*0.1100*	*0.1186*	*0.1173*	*0.1158*
	XYZ	*0.9961*	*0.9941*	*0.9969*	*0.9969*
	YCbCr	*0.0690*	*0.0958*	*0.0956*	*0.0958*
	YUV	*0.0365*	*0.0885*	*0.1018*	*0.0989*
FRAME 5	**RGB**	*0.1196*	*0.1226*	*0.1194*	*0.1196*
	XYZ	*0.9958*	*0.9937*	*0.9967*	*0.9967*
	YCbCr	*0.0698*	*0.0959*	*0.0956*	*0.0958*
	YUV	*0.0393*	*0.0914*	*0.1040*	*0.1009*
FRAME 6	**RGB**	*0.1230*	*0.1261*	*0.1260*	*0.1236*
	XYZ	*0.9964*	*0.9944*	*0.9972*	*0.9972*
	YCbCr	*0.0705*	*0.0961*	*0.0959*	*0.0961*
	YUV	*0.0292*	*0.0807*	*0.0954*	*0.0941*
FRAME 7	**RGB**	*0.1078*	*0.1103*	*0.1075*	*0.1072*
	XYZ	*0.9963*	*0.9940*	*0.9969*	*0.9969*
	YCbCr	*0.1589*	*0.1595*	*0.1597*	*0.1598*
	YUV	*0.0291*	*0.0656*	*0.0757*	*0.0737*
FRAME 8	**RGB**	*0.1113*	*0.1141*	*0.1111*	*0.1111*
	XYZ	*0.9961*	*0.9941*	*0.9970*	*0.9969*
	YCbCr	*0.1435*	*0.1604*	*0.1602*	*0.1606*
	YUV	*0.0782*	*0.1149*	*0.1312*	*0.1234*
FRAME 9	**RGB**	*0.1065*	*0.1090*	*0.1055*	*0.1058*
	XYZ	*0.9960*	*0.9941*	*0.9969*	*0.9970*
	YCbCr	*0.1304*	*0.1582*	*0.1576*	*0.1582*
	YUV	*0.0011*	*0.0399*	*0.0482*	*0.0457*
FRAME 10	**RGB**	*0.1097*	*0.1121*	*0.1075*	*0.1090*
	XYZ	*0.9959*	*0.9937*	*0.9967*	*0.9967*
	YCbCr	*0.1011*	*0.1532*	*0.1521*	*0.1531*
	YUV	*0.0114*	*0.0724*	*0.0882*	*0.0848*

Table.1 consists of SSIM values for 10 Live Video frames. Mean Structural Similarity Index measurement (SSIM) Values are calculated and tabulated in Table.1 for RGB, YUV, YCbCr and XYZ color models by applying Sobel, Robert, Prewitt's and Laplacian operators.

Fig. 1, ORIGINAL LIVE VIDEO FRAME

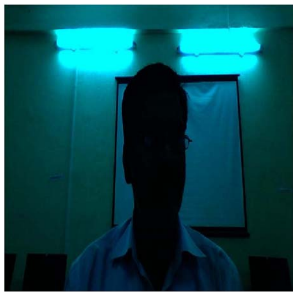


Fig. 2, EDGE DETECTED X COMPONENT BY SOBEL

Fig. 3, SSIM VALUE OF X BY APPLYING ROBERT OPERATOR IS : 0.9949

Fig. 4, SSIM VALUE OF X BY APPLYING LAPLACIAN OPERATOR : 0.9964

Fig. 5, EDGE DETECTED X COMPONENT BY PREWITT OPERATOR

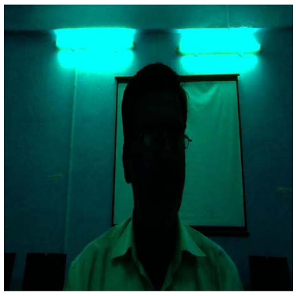


Fig. 6, EDGE DETECTED X COMPONENT BY ROBERT OPERATOR

Fig. 7, EDGE DETECTED X COMPONENT BY LAPLACIAN OPERATOR

Fig. 8, EDGE DETECTED Y COMPONENT BY SOBEL OPERATOR

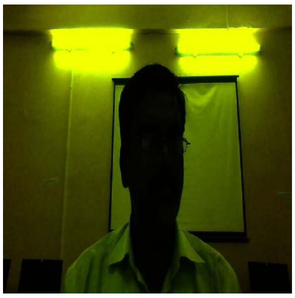


Fig. 9, EDGE DETECTED Y COMPONENT BY ROBERT OPERATOR

Fig. 10, FEDGE DETECTED Y COMPONENT BY PREWIT OPERATOR

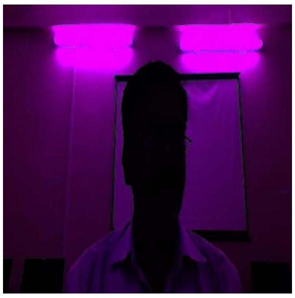


Fig. 11, EDGE DETECTED Z COMPONENT BY SOBEL OPERATOR

Fig. 12, EDGE DETECTED Y COMPONENT BY LAPLACIAN OPERATOR

Fig. 13, EDGE DETECTED Z COMPONENT BY PREWIT OPERATOR

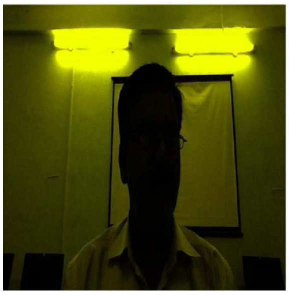


Fig. 14, EDGE DETECTED Z COMPONENT BY ROBERT OPERATOR

Fig. 15, SSIM VALUE OF X COMPONENT BY APPLYING SOBEL OPERATOR IS : 0.9964

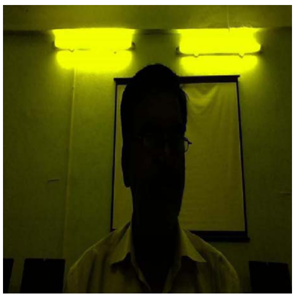


Fig. 16, EDGE DETECTED Z COMPONENT BY LAPLACIAN OPERATOR

Fig. 17, SSIM VALUE OF Y COMPONENT WITH Cb,Cr BY APPLYING SOBEL OPERATOR IS : 0.1888

Fig. 18, SSIM VALUE OF X COMPONENT BY APPLYING PREWIT OPERATOR IS : 0.9964

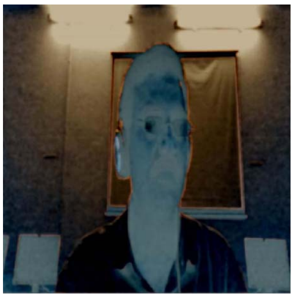


Fig. 19, SSIM VALUE OF RED COMPONENT WITH GREEN & BLUE BY APPLYING LAPLACIAN OPERATOR IS : 0.0218

Fig. 20, SSIM VALUE OF Cb COMPONENT WITH Y &Cr BY APPLYING LAPLACIAN OPERATOR IS : 0.2432

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