EE5356 Project Assignment 3A: Color Transformation.

The purpose of this project is to obtain knowledge of image representation in color space, get hands on experiences of color conversion between different color spaces, and understand their application in video compression. The test image, flowers.bmp (500x362), for this project is available at the class website. Note that in video/image coding international standards this is required.

Question*:*

1. Read the given color image (flowers.tiff) into MATLAB and decompose it into R,G,B components and show those images respectively in your report.

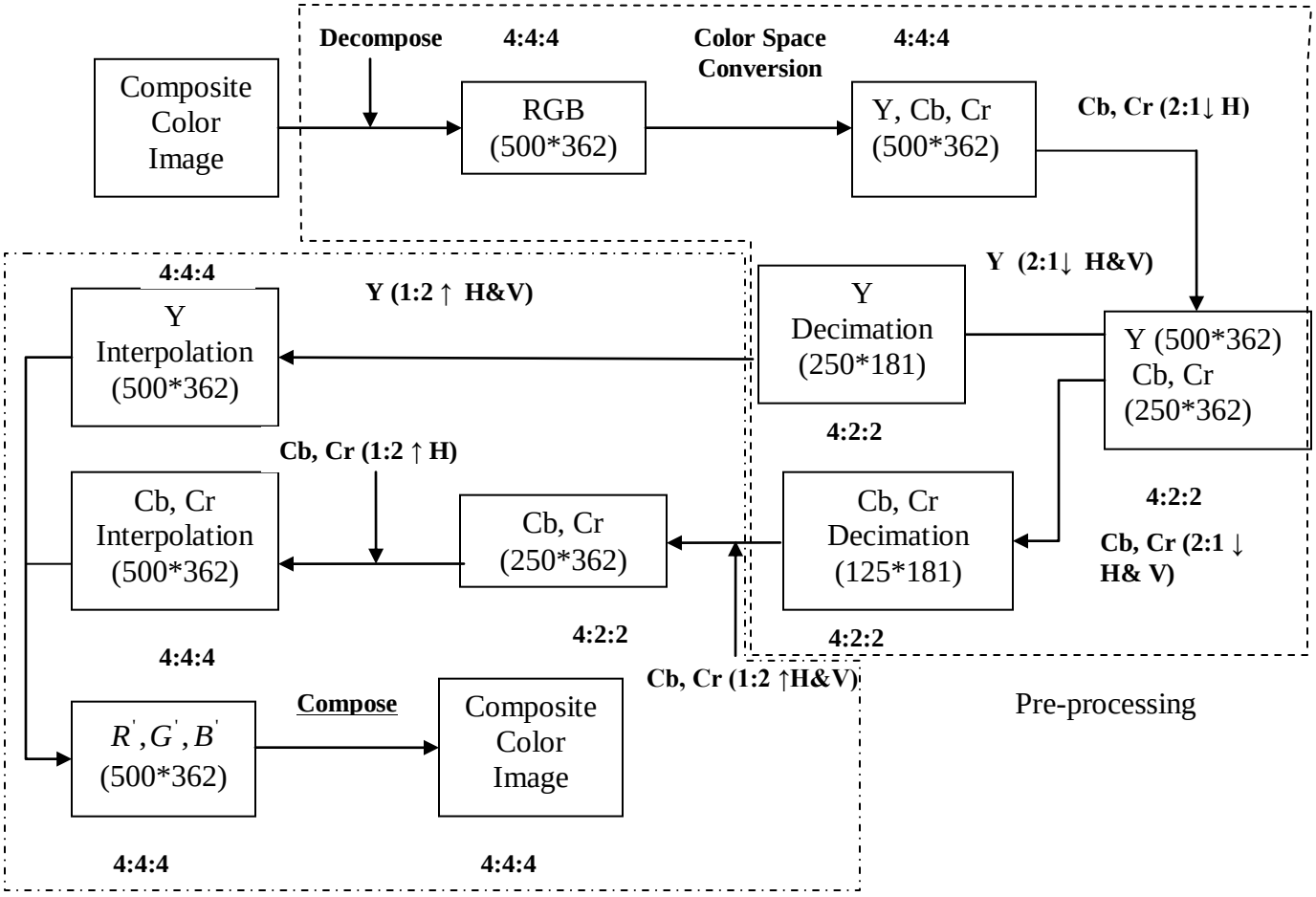
2. Perform color space conversion from R, G, B to Y,Cb,Cr, and show each component image respectively in your report.

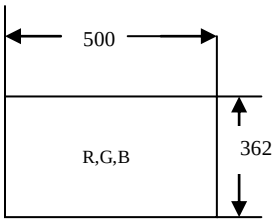
3. Perform downsampling in YCbCr domain to form 4:2:2 format, then apply luminance and chrominance decimation filters followed by interpolation filters and upsampling to original resolution and inverse conversion to $R^{'}, G^{'}, B^{'}$, show the reconstructed images.

Y: Luminance
Cb, Cr: Color difference signals

Note:

1. Experimental procedure:

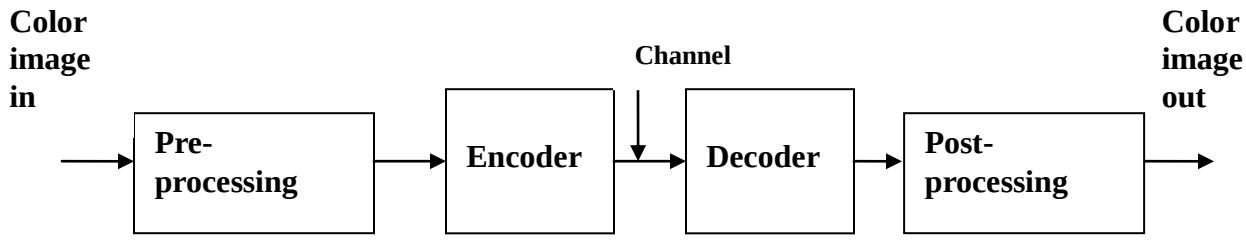




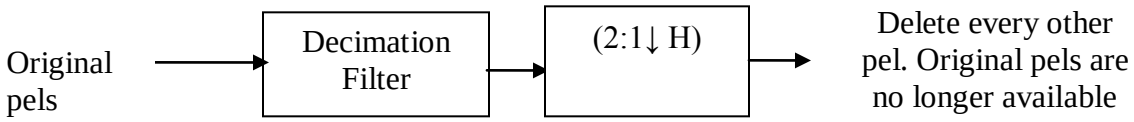
Notation:

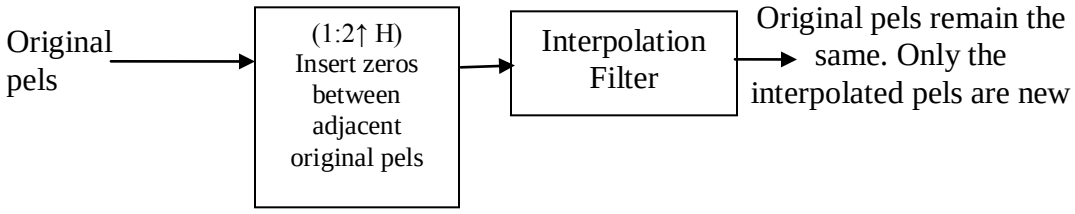
2:1 ↓H- Decimation horizontally by 2:1
2:1 ↓V- Decimation vertically by 2:1
2:1 ↓H&V- Decimation both horizontally and vertically by 2:1
1:2 ↑ H – Interpolation horizontally by 1:2
1:2 ↑ V - Interpolation vertically by 1:2
1:2 ↑ H&V - Interpolation both horizontally and vertically by 1:2

Block Diagram:



Note that this pre/post processing is used in the video coding standards. However pre/post processing is not part of the standards. This is left to the designer.





Note that from decimation/ interpolation filters, one can obtain their frequency responses.

2. YCbCr signals are obtained form digital gamma-corrected RGB signals as follows:

$$Y=0.299R+0.587G+0.114B$$
$$Cb=-0.169R-0.331G+0.500B$$
$$Cr=0.500R-0.419G-0.081B$$

$$\begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.169 & -0.331 & 0.500 \\ 0.500 & -0.419 & -0.081 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

Given the data range for Y is [16 235], and the data range for Cb, Cr is [16, 240], the signal has to be scaled to obtain the decimal value. The conversion equations are expressed as below

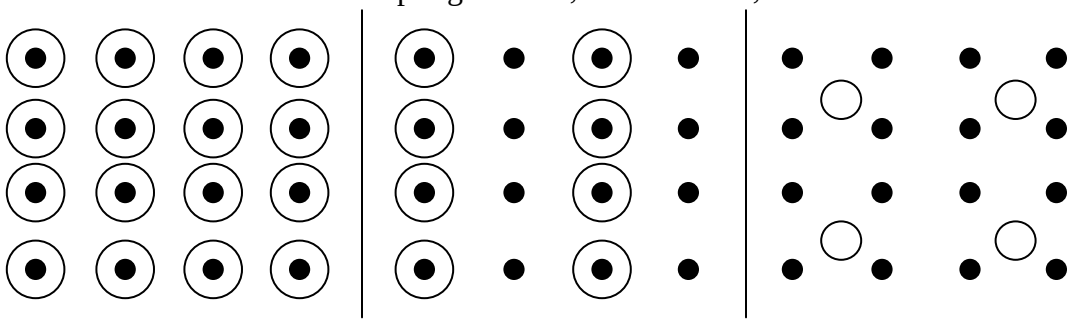
Y=0.257*R+0.504*G+0.098*B+16;
Cb=-0.148*R-0.291*G+0.439*B+128;
Cr=0.439*R-0.368*G-0.071*B+128;

$$\begin{bmatrix} Y \\ Cb \\ Cr \end{bmatrix} = \begin{bmatrix} 0.257 & 0.504 & 0.098 \\ -0.148 & -0.291 & 0.439 \\ 0.439 & -0.368 & -0.071 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} + \begin{bmatrix} 16 \\ 128 \\ 128 \end{bmatrix}$$

R=1.164(Y-16)+1.596(Cr-128)
G=1.164(Y-16)-0.813(CR-128)-0.392(Cb-128);
B=1.164(Y-16)+2.017(Cb-128);

$$\begin{bmatrix} R \\ G \\ B \end{bmatrix} = \begin{bmatrix} 1.164 & 0.000 & 1.596 \\ 1.164 & -0.392 & -0.813 \\ 1.164 & 2.017 & 0.000 \end{bmatrix} \begin{bmatrix} Y-16 \\ Cb-128 \\ Cr-128 \end{bmatrix}$$

3. There are several YCbCr sampling formats, such as 4:4:4, 4:2:2 and 4:2:0



4:4:4 4:2:2 4:2:0

Y sample Cb,Cr samples

4. Decimation and interpolation filters are used for Y

Luminance Decimation Filter:

-29	0	88	138	88	0	-29

// 256

Luminance Interpolation Filter:

-12	0	140	256	140	0	-12

//256

5. Decimation and interpolation filters are used for Cb,Cr in format conversion from 4:4:4 to 4:2:2 and 4:2:2 to 4:4:4 respectively

1	3	3	1

// 8

Cb,Cr decimation filter

1	0	3	8	3	0	1

// 8

Cb,Cr interpolation filter

// denotes integer division with rounding to the nearest integer

Hint for 4, 5:

The 4:2:2 standard requires that the color difference signals (Cr and Cb) are sub-sampled with respect to the luminance by 2:1 in horizontal direction. Then Y is (500*362) and Cb, Cr are (250*362). For Y is (250*181) and Cb, Cr are (125*181), the resolution is also 4:2:2.

Pre-processing:
The interpolation filter applied to a zero-padded signal can be chosen to be equal to the decimation filter employed for luminance and the two chrominance values in the encoder. The chrominance samples have to be placed at a horizontal position in the middle of the luminance samples. A linear filter with a phase shift of ½ a sample is used for this task.
In pre-processing, the optimum resolution represents a tradeoff between the various coding artifacts (eg: noise and blockiness) and the perceived resolution and sharpness of the image.

Post-processing:
A linear phase FIR-filter is applied after the insertion of zeros between samples.

Example:
Image data samples excerpted from a picture.
At the end of lines, last pels are replicated at the both ends of the pel array.

Note that the luminance interpolated pels that correspond to the position of decimated outputs are the same. The rest are calculated using the formula given for luminance interpolation filter.

Input pels	y0	y1	y2	y3	y4	y5	y6	y7	y8	y9
	80	76	79	75	79	82	82	86	94	85
Decimated pels		ŷ1		ŷ3		ŷ5		ŷ7		ŷ9
		78	0	76	0	80	0	88	0	88
Interpolated pels	A0	ŷ1	A2	ŷ3	A4	ŷ5	A6	ŷ7	A8	ŷ9
	78	78	77	76	78	80	84	88	89	88

$$\hat{y}\,5 = [138*y5 + 88*(y4+y6) - 29*(y2+y8)]//256$$

$$A4 = [140*(\hat{y}\,3 + \hat{y}\,5) - 12*(\hat{y}\,1 + \hat{y}\,7)]\,//256$$

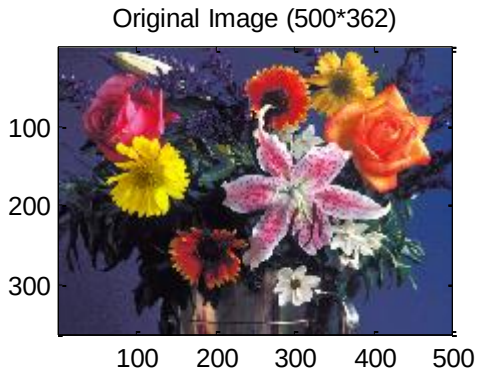
The nonlinear filter is designed for pre- and post-processing with respect to the filtering points:

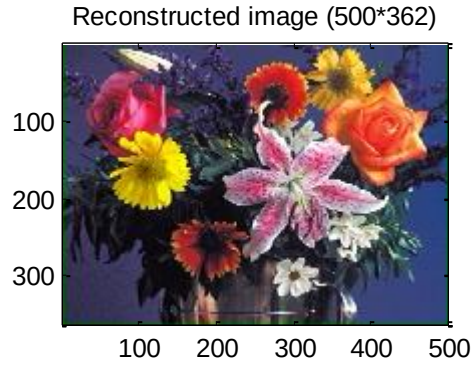
1. The filtering reduces the aliasing effects
2. It gives smooth transmission region and reduces the visibility of false contours, and it retains image sharpness.

Figures are given next page onwards..

FIGURES:

Original and Reconstructed Composite Color Images:





RGB and YCbCr components of size 500*362:

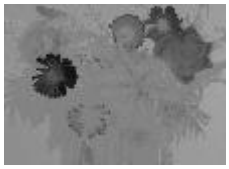
Red Component

Green Component

Blue Component

Luminance Y

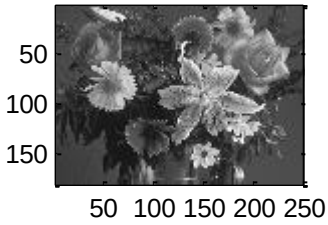
Chroma Cb



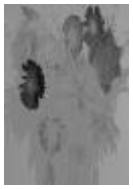
Chroma Cr

Luminance and Chrominance Decimated and Interpolated Images:

Luminance Decimated Image(250*181)

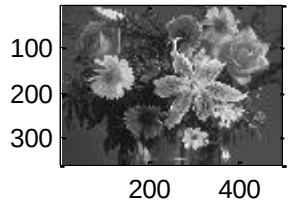


Cb Decimated Image(125*181)

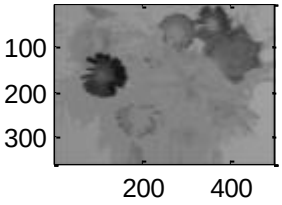


Cr Decimated Image(125*181)

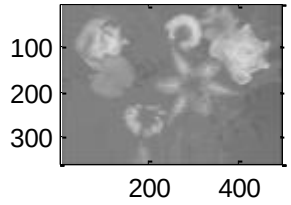
Luminance Interpolated Image(500*362)



Cb Interpolated Image (500*362)

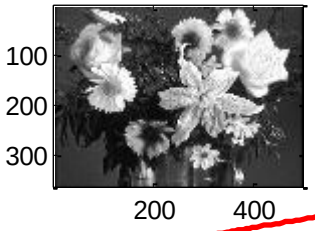


Cr Interpolated Image (500*362)



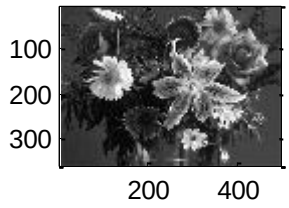
Reconstructed Color Components:

Reconstructed Red Component (500*362)

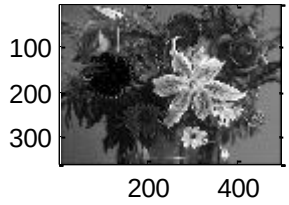


BLUE

Reconstructed Green Component (500*362)



Reconstructed Green Component (500*362)



Frequency Response Outputs:

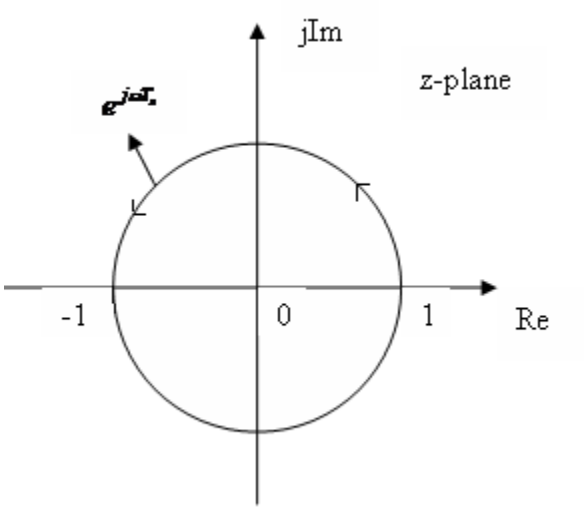
Luminance Decimation Filter:

ŷ 5= [138*y5+ 88* (y4+y6) -29* (y2+y8)]//256

Applying z-transform to the above filter

$$H(z) = \frac{1}{256}[138 + 88(z^{-1} + z) - 29(z^{-3} + z^{3)}]$$

Substitute z = $e^{j\omega T_s}$

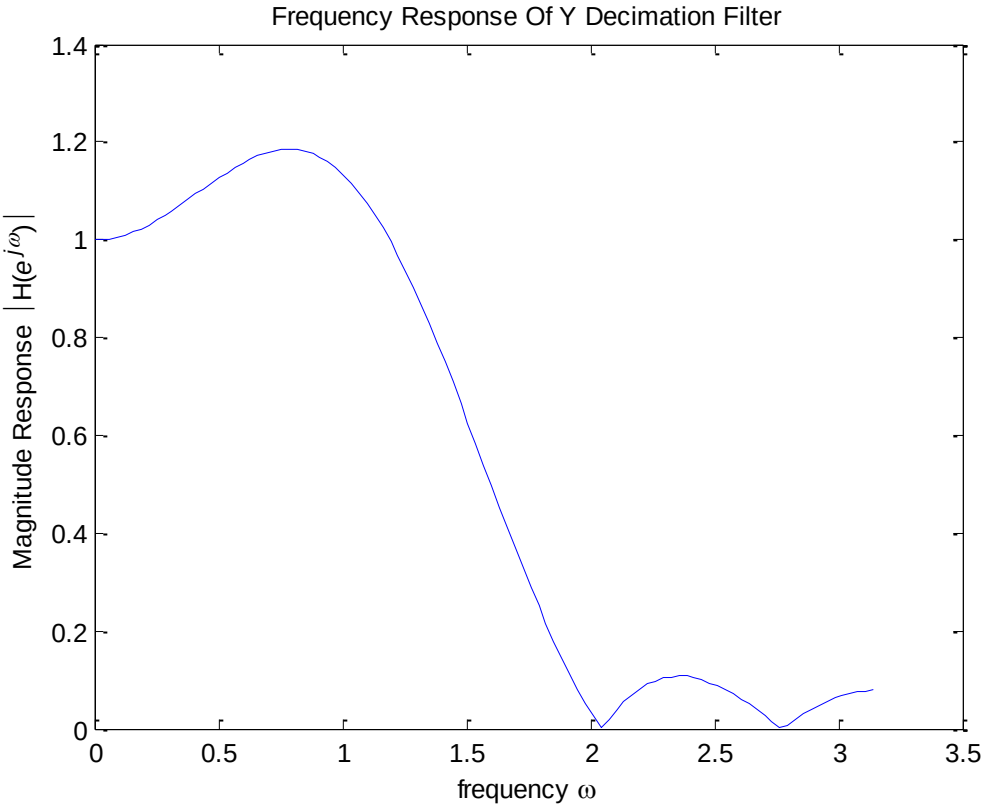


Frequency Response of the filter is given as

$$H(e^{j\omega T_s}) = \frac{1}{128}[69 + 88\cos\omega T_s - 29\cos 3\omega T_s]$$

Use T_s =1,

$$H(e^{j\omega}) = \frac{1}{128}[69 + 88\cos\omega - 29\cos 3\omega]$$



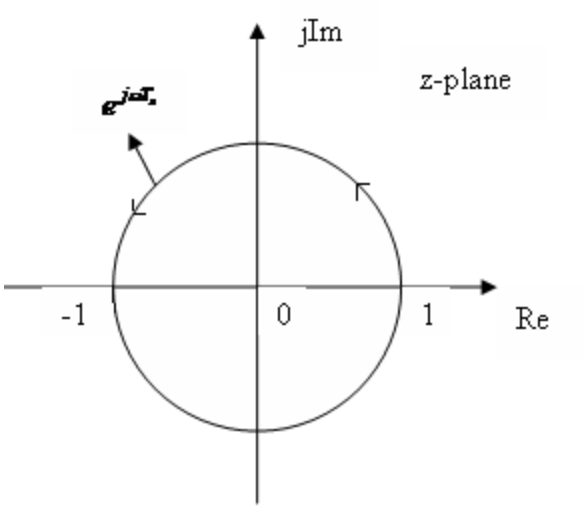
Luminance Interpolation Filter:

A4= [256+140* (ŷ 3+ ŷ 5) -12* (ŷ 1+ ŷ 7)] //256

Applying z-transform to the filter

$$H(z) = \frac{1}{256}[256 + 140(z^{-1} + z) - 12(z^{-3} + z^{3})]$$

Substitute z = $e^{j\omega T_s}$



Frequency Response

$$H(e^{j\omega T_s}) = \frac{1}{128}[128 + 140\cos\omega T_s - 12\cos 3\omega T_s]$$

Use T_s =1,

$$H(e^{j\omega}) = \frac{1}{128}[128 + 140\cos\omega - 12\cos 3\omega]$$