Colorizing Grey Scale Images

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Abstract
The purpose of this thesis is to develop a working methodology to color a greyscale image. This thesis is based on approach of using a colored reference image. Coloring greyscale images has no exact solution till date and all available methods are based on approximation. This technique of using a color reference image for approximating color information in greyscale image is among most modern techniques.
Method developed here in this paper is better than existing methods of approximation of color information addition in greyscale images in brightness, sharpness, color shade gradients and distribution of colors over objects.
Color and greyscale images are analyzed for statistical and textural features. This analysis is done only on basis of luminance value in images. These features are then segmented and segments of color and greyscale images are mapped on basis of distances of segments from origin. Then chromatic values are transferred between these matched segments from color image to greyscale image.
Technique proposed in this paper uses better mechanism of mapping clusters and mapping colors between segments, resulting in notable improvement in existing techniques in this category.
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Chapter 1

Introduction

Color image contains more information than a greyscale image and in most of scenarios color image is more useful to extract information from image. Color images are vivid and visually appealing to viewers. Coloring a grey scale image is a hot and tough topic in image processing since it involves information re-generation. Its uses range from coloring old black and white photos and movies to scientific illustrations.

Color image consists of three dimensional information about the color of image. Which are defined by red green and blue, whereas a greyscale image consists of luminance and hence it is one-dimensional. Converting a color image to grey means that we are dropping information about color and it is quite easy to convert color image to greyscale but its reverse is not that easy. It looks like that we can reverse the process of converting a color image to grey to get colors back, but it’s not that true. Reason for this is that there can be numerous colors which lead to one grey level but when we go reverse of it, we cannot decide which color corresponds to this one particular grey level which we are trying to convert to color.

This problem has no exact solution yet, because of the fact that there is no deterministic relation between the luminance of grey image and exact colors of the same image if it was a colored image. Efforts done to formulate a solution to this problem can be categorized in 2 categories, Manual and Semiautomatic.

Manual Coloring

In a “Manual Coloring”, we have to color different parts of the image by our perception of colors of the grey image. Talking about digital images, we have to select a color for each pixel in the grey image and thus you can get the job done. But obviously is very tedious, time taking and requires human vision of proposed color of grey pixel.

Semiautomatic Coloring

“Semiautomatic Coloring” techniques make this job easier and we can segment grey image and then we can use some predefined colors to be applied to these segments. An example can be “BlackMagic” software[1]. It actually segments grey image and then user can select predefined color brushes to be applied on these segments. Results of this software are not satisfactory and not close to reality.

Advanced Semiautomatic Coloring

Modern semiautomatic techniques do not require much human intervene for coloring grey images and are mostly based on a method proposed by Welsh et al[2]. This method suggests that for coloring a grey image we should have a similar color image and then we transfer color information form color image to grey image on basis of mean intensity and standard deviation calculated on neighborhood of the pixel. This pixel is called seed pixel and we have to select the seed pixel in color and in grey image to perform this algorithm. Hence in this way we select different seed pixels in both images depending on color variation. This method works well but it involves human intervene, in terms of swatches selection, to get job done.

In 2010 a Novel Coloring Framework[3] was proposed which further minimized human interaction in this process. According to this approach, we use statistical and texture feature of grey and color image and then we cluster them using k-means algorithm. Then we map these clusters on basis of distance of clusters from center and then we transfer colors from color image clusters to grey image clusters.
Problem definition

Greyscale image is without any information of chromatic values and there is no established method to find any relation between them. We see that coloring greyscale images actually means addition of chromatic values to grey image by regeneration of chromatic values for pixels in colors. This regeneration of chromatic values according to grey image is actual problem. We are not able to regenerate exact information of chromatic values but we can make some approximation by using a reference color image. We can have a color image and we can create some relation between the color image and the grey image. Based on this relation we can transfer colors from reference image to color image. Using a reference image gives us a ground to work further for making approximations. How we can relate luminance with chromatic values? How we can get better color shades by using reference image? Goal and objective of this thesis is to find a better way for colorizing of greyscale images in category of Advanced Semiautomatic Coloring technique.
Chapter 2

To understand this enhanced method, it is important to understand what are colors and how our eyes perceive them, what are color spaces and what are grey and color images. Beside this we also need to have an insight of existing state of art methods for getting grey image colored. This understanding makes it easier to explain and understand proposed method for coloring grey images.

2.1 Theoretical Background

Since colorizing grey image involves greyscale, color spaces and while using reference image for approximation, we need to do some texture analysis and clustering, so I will explain these before heading forward.

2.1.1 Greyscale Images

A greyscale image is an image which is represented by intensity only. Value of this intensity defines the appearance of a certain pixel in an image. Lowest value of intensity or its absence in a greyscale image is represented with black color and its highest value represents white color. All values between these highest and lowest represent shades of grey. These number of shades are dependent on possible values which a pixel may hold. If pixel is represented by a bit, then it can hold two values, 0 and 1 and thus we get a pure black and white image with no grey shades. If this pixel is represented by a byte value, then we can have 256 grey levels starting with 0 as black and ending with 255 as white. So this way as we increase number of bits for representation of pixel, grey levels increase with it.

Intensity which is only property with greyscale image, is represented by this value of representation of greyscale. If this intensity/luminance is more, pixel’s shade is closer to white and vice versa.

2.1.2 Color Images

A color image is an image which is represented by some color space. This color space is not dependent on only one value like greyscale image. Each pixel in color image is represented by more than one value and combined effect of these values gives appearance of a color. Before heading into these color spaces, we need to understand how our eyes sense colors.

Our eyes consist of Rod and Cone cells. Rod cells are designed to feel intensity of light whereas Cone cells are designed to sense color of light which falls on retina of eye. Cone cells are usually of three types, named Short, Medium and Long. Short cones are sensitive to shorter wavelengths of light meaning they sense Blue color. Medium cones are sensitive to medium wavelengths and hence they sense green color and similarly Long cones, sense Red color because of their sensitivity to long wavelengths.

Based on this a color space is designed which is named as RGB color space.
2.1.3 RGB Color Space
RGB color space is designed with perspective of human sense of color perception. Talking with perspective of computer graphics, this color space represents each pixel with three values of Red, Green and Blue. Each pixel on screen represents 3 light emitting devices, which emit R, G and B to represent color of that pixel and our S, M and L cones receive these lights and combined effect of these is that we see some color.
If each color is defined by a byte, then we can have 256 shades of each color, which in result, give us a vast variety of colors with 256 shades of each color. This color space is designed for representing colors with electromagnetic systems, like computers, television, printers etc where human need to sense them.
Though RGB is the desired for human sense, but its not good for processing and performing calculations in image processing. Also this space is not device independent. Image processing usually involves other color spaces and relevant to this work is \( L\alpha\beta \) color space. More information about color spaces can be found at [11].

2.1.4 \( L\alpha\beta \) Color Space
A \( L\alpha\beta \) color space consists of 3 parts \( L, \alpha \) and \( \beta \). Here \( L \) is luminance, \( \alpha \) represents values from green to magenta and \( \beta \) represent values from blue to yellow.
In this color space, 0 value of \( L \) represents absence of luminance and higher values represent presence of luminance. Lower values of \( \alpha \) represent presence of green and higher values represent magenta and between them are variances from green to magenta. Similarly, lower values of \( \beta \), represent blue and higher values represent yellow.
\( L\alpha\beta \) color space is widely used in image processing. Particularly in this work, \( L\alpha\beta \) is used because of the fact that this color space minimizes effect of correlation between color channels and so if we make any change in one channel, it does not effects the other channel.
However this color space belong to chromatic value color space and is not suitable for human perception of colors, though its very useful in processing colors. Further information about importance of this color space can be found at [12].

2.1.5 Texture
Texture is defined as a block structure with some properties in its domain of use. Talking about textures in image processing it is defined as block of elements in an image which repeats in that image. Texture can be divided in two main categories, structured and stochastic textures. A structured texture is a texture of regular repeating shapes, its example is bricks on a wall or tiles on floor. A stochastic texture is a texture which has no regular pattern or min and max luminance or color. This kind of texture looks like a noise. Its example can be an image of sand in desert. Most of images from natural scene are of 2nd type of texture. For further reading please go here [6].

2.1.6 k-Means Clustering
k-Means is a cluster analysis technique used to cluster given n samples of data into k number of clusters. This algorithm attempts to clusters the given set of data into clusters on basis of euclidean distance such that this distance is minimized. This method of segmentation works on an unsupervised learning method. Number of clusters are input to this algorithm.
This algorithm allocates random $k$ number of initial means on basis of mean of data set and points in dataset are gathered around these centroids on basis of euclidean distance. In next step these centroids are updated and points are rearranged again according to distance of points from centroids. These steps are repeated until there is no change in intercluster distance.

Suppose that we have feature vectors containing $n$ elements, and we want to cluster it into $k$ clusters. It is important to mention that number of clusters should be less than number of samples in feature vector, meaning $k < n$. Now let $m_i$ be the mean of the sample vectors in cluster $i$. Following is procedure for finding the $k$ means:

- Make initial guesses for the means $m_1, m_2, ..., m_k$
- Continue till change in any mean among $m_1, m_2, ..., m_k$
  - Classify the samples into clusters according to these means
  - For $i$ from 1 to $k$
    - Replace old mean $m_i$ with new mean for this cluster $i$
  - End for
- End continue

This algorithm continues until there is no change in means is observed, resulting in minimized intercluster distances with $k$ clusters. Further information about k-Means can be found at [8].

2.1.7 Histogram

Histogram of an image is usually a bar graph between grey levels and number of pixels contained in that grey level. For a color image in RGB space, 3 channels named R, G and B may replace grey level independently resulting in 3 histograms of these 3 color channels. Horizontal axis of graph represents grey level/color channel level and vertical axis represents number of pixels in that level.

Histogram of an image helps us to judge the tone distribution of image. Histogram help us to judge, whether an image is bright, dark, high contrast or low contrast etc. For example if histogram of an image is more inclined towards the origin of the graph, it is a dark image as compared to the image whose histogram is inclined away from origin of graph. Similarly if graph is shrink in middle, then it is low contrast image as compared to image whose graph spreads all over the graph. These properties of histograms help us to analyze images. More information about histograms and its analysis can be found here [9] and here [10].

2.2 Literature review

For colorizing grey images, there are two prominent research works in this field.

- “Transferring Color to Greyscale Images”.[2]
- “A novel coloring framework for grayscale images”.[3]

Both of these fall in semi-automated technique for colorizing grey image since both require human intervene to some extent. “A novel coloring framework for grayscale images” since it
is more advanced technique and it is more inclined towards fully automated colorization of greyscale images.
Both of these techniques use a reference image to get color information and transfer this color information to greyscale image.

2.2.1 Transferring Color to Greyscale Images
This technique involves sampling a subset of color image as samples. Then in an iterative way we go through the greyscale image in scan line order and select the best sample from color image. This matching is based on neighborhood statistics of the pixel and best match is based on weight of luminance and neighborhood statistics. Next, chromatic values of best matched sample of color image are transferred to greyscale image. In next phase of this technique, some swatches are used where human select some portions of color image and its matching greyscale image portion. Colors from the region defined by these swatches is then transferred to the non-colorized pixels in a texture synthesis way. This algorithm basically consists of two parts.
- Global image matching
- Swatches

Global image matching
As a first step, color and grey images are converted to Laβ space for further processing. For further processing L part from Laβ color image is used.
Second step in this phase is luminance remapping[5]. This is done by linearly shifting and scaling the luminance histogram of the color image such that it fits the histogram of grey image. This removes the global luminance difference in color image with comparison to grey image.
Next standard deviation of luminance is calculated for each pixel. This paper suggests 5x5 neighborhoods for most of the images.
Now next samples are taken from color image grid. This selection is done randomly. Paper suggests that approximately 200 samples are enough. Though number of samples can be increased but it will increase the number of comparison for each pixel with these samples. Paper states, that experimental results show that 200 samples are enough to perform this operation with significant results.
In matching process, best matching sample is selected on basis of weighted average of luminance and standard deviation. Both luminance and standard deviation are given 50% weightage. Once a best matching pixels is found in sample, its chromatic values are transferred to greyscale image. The regions in the target image which do not have a close luminance value to a sample in the color image will not appear correct.

Swatches
This process involves human intervene for improvement of results. For this swatches are used between corresponding regions in the two images. In this step process is same as above, only difference is that now colors are transferred only between the corresponding swatches. This allows the user to selectively transfer colors between the source and target swatches. Luminance remapping is done between corresponding swatches.
Here approximately 50 samples per swatch are taken.
2.2.2 A novel coloring framework for grayscale images

This technique consists of five major steps to transfer colors from a color image to a greyscale image. These steps are:

- Color space conversion
- Preprocessing
- Feature extraction
- Clustering/Segmentation
- Color transfer

**Color space conversion**

The first step in this process is to convert the color space from RGB to Lαβ. These details of conversion from RGB to Lαβ are described by Ruderman et al. [4]

**Preprocessing**

Next, scaling luminance is done in order to adjust the luminance of the color image. This histogram scaling of color image should be done such that it fits the histogram of the grey image. Rather than using histogram matching, this framework uses linear mapping method, which is proposed by Hertzmann et al. [5]

**Feature extraction**

In this process we extract features of color image and greyscale image. Based on these features we will cluster them for similarities. This framework proposes seven feature set for color and for grey image. Result of this step is that we will have feature sets of color and grey images containing 3 statistical and 4 texture features.

This method uses a larger, 7 feature set whereas, Welsh et al. method uses the mean and standard deviation of a small neighborhood around each pixel only. So this method gives better discrimination between pixels that have similar luminance values.

Last action in this step is to normalize the feature sets. These 7 features in each image are normalized to the range of -1 and 1 before performing going next.

**Clustering/Segmentation**

This framework uses K-Means algorithm for clustering the feature vectors. K-Means clusters the pixels in image into specified number of clusters by an unsupervised learning mechanism such that the distance between clusters is minimized. Result of this step is that we get clusters with their centers, pixels contained in them and distance of each pixel from the center of the contained cluster.

Practically, this step needs a preprocessing with feature matrix. This processing involves adding pixel number information to the feature matrix prior to segmentation, otherwise within a segment, we will not be able to identify locations of pixels in the image. Further here user has to provide the number of clusters for segmentation and this step actually keeps it in category of semi-automated.

**Color transfer**

Lists of pixels and inter-cluster feature distance are sorted in increasing order. Next step in this framework is to transfer colors from color image to greyscale image.

This mapping of cluster is done on base of this inter cluster distance. Cluster from grey image is matched with cluster from color image on base of minimum Euclidian distance. This distance is calculated between centers of clusters in 7 feature space. Next preparation of the clusters for color transfer is done. For this both matched clusters are made equal in number of pixels so that we can transfer pixel to pixel color. In case that number of pixels in cluster is not equal in both, color and grey image, these numbers are needed to be made equal. In case
that color cluster contains more pixels than grey cluster, a linear scaling is required in color image cluster such that lowest and highest value of feature vector distance in color image cluster match with lowest and highest values of feature vector in grey image cluster. In case that number of pixels in color image cluster is less than number of pixels in grey image cluster, replication of values in feature vector distance is done starting from lowest values of feature vector distance. Reason for replication of lower values is chosen because of the fact that the higher values replication results in noisy pixels. This process results in equal number of pixels in matched pair of clusters. Next, chromatic values of Lαβ are copied from pixels in color image cluster to pixels in grey image clusters. Finally convert image back to RGB color space, since we converted color image to Lαβ color space for going through this processing.
Chapter 3

We had seen different approaches to color greyscale images and latest techniques of this approximation involve a reference image to be used for getting color information. Another factor involved in these methods is minimization of human intervention in this process. Welsh et al. proposed this basic technique, which was further modified by Novel Framework. Here in this chapter I am proposing a further enhanced approach to improve results obtained in this approximation of coloring.

3.1 Enhanced method for Colorizing Grey Images

Technique described here fall in "Advanced Semiautomatic Coloring”. This technique is based on Welsh et al. method of using a reference image for getting approximate colors, but unlike this method, it minimizes human intervene, it dosent uses swatches for matching similar parts in images.

This automated technique of matching similar parts is based on analysis of images on basis of some statistical features and some textural features. These features help us to recognise different parts of image on basis of statistical and textural properties of image and then segmenting them according to features as used in Novel Framework.

This method uses different technique to match these segments of color and greyscale images and then transfer of colors between pixels as proposed by Novel Framework. This method uses "Forced Mapping” to map clusters in color and grey images and color transfer between pixels based on feature vector distance of pixel.

Result of this is that we get better approximation as proposed by Welsh et al., advanced semi-automation as proposed by Novel Framework and better cluster mapping and color transfer proposed by this method which results in better and closer to reality colors, better color distribution and better shades. It also makes sure that most of the color information from color image is used for approximation of color in grey image.

This technique consists of following steps to transfer colors from a reference color image to a greyscale image.

- Color space conversion
- Histogram Scaling
- Statistical Feature extraction
- Texture Feature extraction
- Feature Unification and Normalization
- K-Means Clustering
- Forced Cluster Mapping
- Color Mapping
- Color space conversion

These steps are shown in following diagram
Figure 3.1 Process Diagram

1. Convert color to Lαβ color space
2. Scale histogram of color image to fit grey image
3. Extract textural features:
   - 1- E5’S5
   - 2- L5’S5
   - 3- E5’L5
   - 4- R5’R5
4. Extract statistical features:
   - 1- Luminance
   - 2- Standard Deviation
   - 3- Mean Deviation
5. Unify statistical and textural features for clustering and normalization
6. k-Mean Clustering
7. Cluster Mapping
8. Color Mapping
9. Convert color space back to RGB
3.1.1 Color space conversion
The first step in this process is to convert the color space from RGB to Lαβ. The reason being that there is correlation between RGB channels which may distort color after processing. Also this RGB space actually corresponds to the way human eye perceives colors, so it is not suitable for color processing in programs. This RGB color space should be changed to Lαβ space where L part represents Intensity, α represents Red-Green and β represents Yellow-Blue channels. This change in color space de-correlates RGB. L part matches more closely to human perception of luminance and we will see later that actually only L part is used in this framework for calculations and this match with human luminance perception gives better results than luminance calculated from RGB values.

My experiments with HSV color space showed that HSV is not suitable for this processing because V is correlated to H and S, so in final transfer combination of H and S values with V value of grey image do not result in expected results.

So Lαβ is best suited for this processing since it has minimal effect of change in its contained chennels on actual color. These details of conversion from RGB to Lαβ are described by Ruderman et al. [4]

3.1.2 Histogram Scaling
Since the color Image and the grey Image can have different luminance levels and only luminance part is used in this processing, so they are not appropriate for feature matching process, they must be brought on same intensity level before processing further. This scaling luminance is important to get proper results otherwise color transferred will barely match.

Since we have to apply colors to grey image, so we have to adjust the luminance of the color image because any change in grey image’s luminance will not result in getting results closer to reality. This histogram scaling of color image should be done such that it fits the histogram of the grey image.

Unlike using histogram matching as described by Welsh et.al[2], Novel framework[3] uses linear mapping method, which is proposed by Hertzmann et al. [5]

New luminance value is calculated by [3]

\[ l_s = \frac{\sigma_t}{\sigma_s} (l_s - \mu_s) + \mu_l \]

Where
- \( l_s \) = Original luminance value.
- \( \sigma_t \) = Mean deviation of grey image
- \( \sigma_s \) = Standard deviation of grey image
- \( \mu_s \) = Mean deviation of color image
- \( \mu_l \) = Standard deviation of color image

Result of this step is that we get both images with same luminance level.

3.1.3 Statistical Feature extraction
In this process we extract statistical features of color image and greyscale image. Based on these features we will cluster them for similarities. Result of this step is that we will have feature sets of color and grey images containing 3 statistical features. It should be kept in mind that we are left with luminance value for color and grey image.
Statistical features included in this method are,

- Luminance
- Mean deviation
- Standard deviation

Inclusion of statistical features ensures that two pixels having different intensities of luminance but same or close mean deviation and standard deviation should be segmented properly. Mean and standard deviation are calculated over NxN neighborhood of each pixel. Different experiments are obtained by 5x5 mask for Mean and standard deviation.

### 3.1.4 Textural Feature extraction

In this step we extract textural features of color image and greyscale image. Novel framework proposes a set of 4 symmetrical and anti symmetrical mask, which are proven to extract textural features and these are included in this method too,

- E5’S5
- L5’S5
- E5’L5
- R5’R5

Texture features are calculated by image texture. These laws [6] propose proposed a set of 1-D filters that can be convolved with the transpose of each other to produce a set of 2-D symmetrical and anti-symmetrical filters. The 1-D filters are,

- \( E5 = [-1 -2 0 2 1] \)
- \( W5 = [-1 2 0 -2 1] \)
- \( S5 = [-1 0 2 0 -1] \)
- \( L5 = [1 4 6 4 1] \)
- \( R5 = [1 4 6 -4 1] \)

These E, W, S, L and R letters stand for filters names Edge, Wave, Spot, Level, and Ripple, respectively and 5 represent the mask size. Only four 2-D masks which are: E5’S5, L5’S5, E5’L5, and R5’R5. These four masks are enough to capture the texture content better than the remaining 2-D masks. The luminance of color and greyscale images is convolved with each of the four masks to produce four corresponding feature images.

### 3.1.5 Feature Unification and Normalization

Here we prepare features sets and pixel identification for clustering. This step results in a feature matrix of size 7xNp where Np is number of pixels in the image for which feature matrix is calculated. Additionally number of pixel in image is added to this list, so that we can recognise this pixel’s reference in image after clustering.

This method uses a larger, 7 feature set whereas, Welsh et al.[2] method uses the mean and standard deviation of a small neighborhood around each pixel only. So this method gives better discrimination between pixels that have similar luminance values. Practically, this step involves processing with feature matrix. This processing involves adding pixel number information to the feature matrix prior to segmentation, otherwise within a segment, we will not be able to identify locations of pixels in the image.

Last action in this step is to normalize the feature sets. These 7 features in each image are normalized to the range of -1 and 1 before performing going next.
3.1.6 k-Means Clustering
Next step is to segment pixels of both color and greyscale images based on these features. This segmentation or clustering has a significant role in this process of color transfer. Idea of this framework is that if we segment pixels of both images then we will find the matching between the clusters and based on this matching we will transfer colors from cluster of color image to matching cluster of greyscale image.

K-Means algorithm is used for clustering the feature vectors. K-Means clusters the pixels in image into specified number of clusters by an unsupervised learning mechanism such that the distance between clusters is minimized. Result of this step is that we get clusters with their centers, pixels contained in them and distance of each pixel from the center of the contained cluster.

Further here user has to provide the number of clusters for segmentation and this step actually keeps it in category of semi-automated.

3.1.7 Forced Cluster Mapping
Clusters generated in previous step contain information about cluster center. Cluster from grey image is matched with cluster from color image on base of minimum Euclidian distance in a forced mapping manner. This distance is calculated between centers of clusters in 7 feature space. This cluster mapping done in a forced mapping manner ensures that all cluster play role in color transfer and none of cluster is ruled out of the process.

Forced Mapping Algorithm:
1. Create a grid of inter cluster distances.
2. Find the lowest value of distance and its corresponding clusters in color and grey image.
3. Assign mapping to these clusters.
4. Exclude these clusters and their distances from grid.
5. Repeat step 2 to step 4 until grid is empty.

In this algorithm, step 4 ensures that one cluster of color image is not mapped with more than one cluster of grey image.

3.1.8 Color Mapping
Next colors from reference color image cluster are transferred to greyscale image cluster. This transfer of color is done by matching the pixel’s distance from centre of cluster. Best matched color is transferred to grey image pixel based on closest distance of corresponding clusters. Chromatic values of αβ are copied from pixels in color image cluster to pixels in grey image clusters. Value of L is retained as of origional grey image.

3.1.9 Color Space Conversion
Final step in this process is to convert color space, since we converted color image to Lαβ color space for going through this processing. And Lαβ is not suited for human perception of colors, so we convert the image back to RGB color space.

3.2 Significance of cluster mapping and choosing color pixel
If we compare this method with existing Advanced Semiautomatic Coloring methods, my proposed method is enhanced in terms of cluster mapping and color transfer technique. This
phase of cluster mapping and color transfer are one of the most important. And this has a
great impact on results.

Cluster mapping plays a vital role in this technique of coloring grey images. This is a step
which defines which cluster’s color will be transferred to which cluster of grey image. If we
see the previous steps, they define and group portions of image on basis of similarities
between statistical and textural features of image under process. However this grouping on
basis of similarity is within an image and it has nothing to do with same process for other
image. This relation between clusters of two images, colored and grey, is define by cluster
mapping. So a very careful decision is required to map clusters for getting results closer to
reality. It is worth noting that equivalent to this mapping, in Welsh et al. method, is swatches
mapping which is done by human intervene. There this decision is taken by human mind and
here in this technique, this decision is taken on basis of distance of clusters from origin.
Clusters are mapped with shortest distance difference between them. There are numerous
possibilities in this process, for example, one cluster in color image may correspond to many
clusters in grey image or vice versa. I explain it with an example, suppose color image has 3
clusters with distances from origin defined by [0.5, 1.8, 2.3] and grey image has 3 clusters
with distances from origin defined by [0.1, 0.8, 1.3]. Now if we see the distance difference
between clusters of color and grey image, we see that cluster 1 of grey image has shortest
difference with cluster 1 of color image and cluster 2 of grey image also has shortest distance
to cluster 1 of color image, similarly cluster 3 of grey image is having minimum distance to
cluster 2 of color image. In this supposed example we see that cluster 1 and 2 of grey image
are mapped to cluster 1 of color image and cluster 3 of grey image is mapped to cluster 2 of
color image.

This means that cluster 3 of color image is not used in this process of mapping and thus the
information of colors contained in cluster 3 of color image will never be used and will not be
transferred to grey image, which might result in colors which are not true or not as much
closer to true, which was possible if cluster 3 was also contained in this process. Also in most
of cases increase in number of cluster will not improve results, since difference in cluster
distance with increased clusters may remain same for comparison. I worked on this and tried
to find out if in such cases, discarded cluster do contain useful colors? Answer I got through
experiments was “yes” and “no”. Yes in a case that color image contains all colors which grey
image would have contained, if it was color image. And “No” in a case that color image
contains more colors than colors in grey image if it was a color image. I is clear that choice of
providing color image for this process is human decision and we can do it carefully to provide
an image which contains almost same colors as grey image would contain if it was a color
image. I experimented with providing color image which contains exactly same colors as
expected to be in grey image, even then I found that in a majority of cases, more than one
clusters of grey image, corresponded to one cluster of color image. This means we were
losing color information, resulting in less colorful result image.

I have a proposed set of enhancements in this approach for better results of coloring. These
enhancements are in process of mapping clusters and in color transfer between clusters. I will
discuss these enhancements one by one.
3.3 Cluster Mapping enhancements

Current approach says that the clusters of color and grey image are mapped on basis of smallest distance between the centers of clusters. Suppose that we have 3 clusters of each image and 2 clusters of grey image have smallest distance to 1 cluster of color image. This approach will assign these 2 clusters of grey image to 1 cluster of color image. This doesn’t give result closer to real colors for grey image. I experimented with another way and I named it “Forced Mapping”. My experiments showed that this results in better cluster mapping.

Now with this enhancement, since all of cluster of color image are used in transferring the color to grey image, it is assured that all color information from the color image will be transferred to grey image which results in brighter and more colors in grey image.

Doing “Forced Mapping” ensures that all clusters from color image are included in process of color transfer to grey image, which is not true with Novel Framework approach in some particular cases and it results in colorizing which is sometimes not true.

However there is one limitation with this “Forced Mapping” to work properly. This limitation is that color image should not contain colors which should not be present in new colored (old grey) image. Since Forced Mapping will force to include all clusters. So selection of color image is requires some consideration about the colors contained in it.

Performing this technique gave me better results, which we will discuss in results section of this report.

3.4 Color transfer enhancement

In case, number of pixels is not equal in matched clusters, this paper suggests an approach. Which says that in case if the number of pixels is less in matched grey image cluster than the number of pixels in color image cluster, a linear scaling is required with caution that lower and higher values of color image cluster matches with lower and higher values of grey image. This technique ensures that chromatic values of pixels with minimum and maximum feature vector distance in color image are included in color transfer process.

On the other hand if the number of pixels is less in color image cluster than grey image cluster, this paper suggest to replicate chromatic values starting from lower feature vector values.

After implementing this, I worked with another approach. My experimental study says that if we equalize imbalanced chromatic values of mapped clusters on basis of feature vector distance, it gives more bright, sharp and close to real colors to grey image.

My proposed enhancement in color transfer does not forces to add or remove repetition of color information contained in a cluster linearly, but this decision of repeating or subtracting chromatic values is proportional to number of values with same distance of feature vector. For doing this, repeated chromatic values are added or removed in proportion to number of chromatic values in mapped cluster on basis of feature vector distance.

My experiments showed that, this proposed enhancement in color transfer avoids sharp boundaries between clusters. This gives quite better shades, avoids sharp color change in shade of cluster and on boundary of clusters.
Chapter 4

To test this proposed method, I implemented it and this implementation is described here in this portion. First I will state tools and environment of implementation and then I will describe implementation steps of this method.

4.1 Implementation Tools and Environment

Implementation is done using Matlab®. Version used is 2010b. Application hosting environment is Microsoft Win7® on Core2Duo® Intel® processor with 3GB RAM. Images used here are royalty free and downloaded from here [8].

4.2 Implementation

Images used during this implementation are shown below and original resolution of images is 400x267.

As I mentioned in previous chapter that this method involves 9 steps, so I will go through implementation of these steps with visual results, where ever it is possible.

4.2.1 Color space conversion

Color image is converted to Lαβ color space and luminance part is extracted in this step, shown in images below

4.2.2 Histogram Scaling

The luminance of color image is scaled to fit the histogram of greyscale image. We can see that the grey image is darker than color image’s luminance and this preprocessing step brings them to same level of luminance by decreasing the luminance of color image.
**4.2.3 Statistical Feature extraction**

In this step 3 statistical features of both images are calculated. Mask used for statistical feature calculation is 5x5. These 3 features are shown in visual form below in tables.

<table>
<thead>
<tr>
<th>Statistical Feature</th>
<th>Color Image</th>
<th>Grey Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminance</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
</tr>
<tr>
<td>Mean deviation</td>
<td><img src="image3" alt="Image" /></td>
<td><img src="image4" alt="Image" /></td>
</tr>
<tr>
<td>Standard deviation</td>
<td><img src="image5" alt="Image" /></td>
<td><img src="image6" alt="Image" /></td>
</tr>
</tbody>
</table>

**4.2.4 Textural Feature extraction**

In this step 4 textural features of both images are calculated. These 4 features are shown in visual form below in tables.

---

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Fax: +46(0)23 778080  
http://www.du.se
<table>
<thead>
<tr>
<th>Textural Feature</th>
<th>Color Image</th>
<th>Grey Image</th>
</tr>
</thead>
<tbody>
<tr>
<td>E5’S5</td>
<td><img src="image1" alt="Image" /></td>
<td><img src="image2" alt="Image" /></td>
</tr>
<tr>
<td>L5’S5</td>
<td><img src="image3" alt="Image" /></td>
<td><img src="image4" alt="Image" /></td>
</tr>
<tr>
<td>E5’L5</td>
<td><img src="image5" alt="Image" /></td>
<td><img src="image6" alt="Image" /></td>
</tr>
<tr>
<td>R5’R5</td>
<td><img src="image7" alt="Image" /></td>
<td><img src="image8" alt="Image" /></td>
</tr>
</tbody>
</table>

Figure 4.7 Textural Feature E5’S5 – Left: Color Image, Right: Grey Image

Figure 4.8 Textural Feature L5’S5 – Left: Color Image, Right: Grey Image

Figure 4.9 Textural Feature E5’L5 – Left: Color Image, Right: Grey Image

Figure 4.10 Textural Feature R5’R5 – Left: Color Image, Right: Grey Image

### 4.2.5 k-Means Clustering
On basis of above 7 features, clustering is done using K-Means algorithm. In this particular example 5 clusters are used for coloring grey image.

For visualization, I colored these clusters. And color legends are
Visualization of clusters is shown below

<table>
<thead>
<tr>
<th>Cluster No</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Red</td>
</tr>
<tr>
<td>2</td>
<td>Green</td>
</tr>
<tr>
<td>3</td>
<td>Blue</td>
</tr>
<tr>
<td>4</td>
<td>Purple</td>
</tr>
<tr>
<td>5</td>
<td>Yellow</td>
</tr>
</tbody>
</table>

Table 4.1 Cluster color legends

4.2.6 Cluster and Color Mapping
This process consists of 3 steps. Cluster mapping, chromatic values transfer and color space conversion.

“Forced Mapping” implementation is shown below and coloring legends are same as described in Table 4.1

For mapping inter cluster distances of color and grey image clusters is given in following table,

<table>
<thead>
<tr>
<th>Grey image clusters</th>
<th>Color image clusters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>0.3303</td>
</tr>
<tr>
<td>2</td>
<td>0.9688</td>
</tr>
<tr>
<td>3</td>
<td>0.1930</td>
</tr>
<tr>
<td>4</td>
<td>0.2189</td>
</tr>
<tr>
<td>5</td>
<td>0.2179</td>
</tr>
</tbody>
</table>

Figure 4.14 Inter cluster distance grid
Figures 4.12 and 4.14 show how forced mapping algorithm worked to map all clusters in color image to all clusters in grey image. If we observe table, we see that 0.1930 is smallest value in the grid and it corresponds cluster 3 in greyscale image to cluster 1 in color image, so cluster 3 in grey image is mapped to cluster 1 of color image. Now for next iterative step, we will assume that row 3 and column 1 do not exist in grid anymore. We again find the lowest value in table, which is 0.2371 and it corresponds cluster 2 in greyscale image to cluster 3 in color image, so cluster 2 in grey image is mapped to cluster 3 of color image. Row 2 and column 3 is also excluded from next search and this process continues till grid is empty. Table 4-4 shows these results of forced mapping.

Number of pixels in each cluster is shown in following table images, also here index represents cluster number and column 1’s values represent number of pixels in that cluster.

Chromatic values transfer on basis of feature vector distances and changing color space back to RGB, gives following results

Figure 4.15 Pixels in clusters – Left: Color Image, Right: Grey Image

Figure 4.16 Result Image – Left: Color Image, Centre: Grey Image Right: Colored grey image
Chapter 5

Experiments were performed on a number of greyscale and color images using this enhanced method, Novel Framework and Welsh et al. methods. I implemented Novel Framework also, using Matlab® and I used same images for both so that we can compare results visually and easily. Welsh et al. method was not implemented, but the images used for comparison were same as used by Welsh et al., so this way we can compare results obtained from this method and result images given in Welsh et al. method [2]. First I will present the resultant images of my enhanced method and then I will compare these with Novel Framework method. Later we will see comparison of this method with Welsh et al. method.

Images used here are royalty free and downloaded from here [8]. For Enhanced Approach Method and Novel Framework Method, grey images were derived from following color images,

![Image of source images for grey images]

These images were converted to greyscale by reducing saturation of color to zero, further they were converted to grey format using matlab.

5.1 Results of Enhanced method

Following are results of implementation of my enhanced method.
Figure 5.2 Enhanced Method Results for Cucumber
Left to Right: Color image, Grey image, Colored grey image with 3 clusters, Colored grey image with 5 clusters

Figure 5.3 Enhanced Method Results for Baby
Left to Right: Color image, Grey image, Colored grey image with 3 clusters, Colored grey image with 5 clusters

Figure 5.4 Enhanced Method Results for Texture
Left to Right: Color image, Grey image, Colored grey image with 2 clusters, Colored grey image with 3 clusters

Figure 5.5 Enhanced Method Results for Leaves
Left to Right: Color image, Grey image, Colored grey image with 2 clusters, Colored grey image with 3 clusters
Results show that as number of clusters is increased, colors become more appealing to human eyes. This is further discussed in statistical analysis of results.

### 5.2 Results of Novel Framework approach

I implemented Novel Framework using Matlab®. As I mentioned earlier, that I will use same reference image and same grey image. This will make visual comparison of results easy. With these results, we can observe a significant improvement in process of colorizing grey image. A subjective visual comparison can be made here. Quantitative analysis follows in next part of this section.

Results obtained with Novel Framework approach are as follows. Pictures for color and grey images and number of clusters used are same as used above.
Figure 5.9 Novel Framework Results for Baby
Left to Right: Color image, Grey image, Colored grey image with 3 clusters, Colored grey image with 5 clusters

Figure 5.10 Novel Framework Results for Texture
Left to Right: Color image, Grey image, Colored grey image with 2 clusters, Colored grey image with 3 clusters

Figure 5.11 Novel Framework Results for Leaves
Left to Right: Color image, Grey image, Colored grey image with 2 clusters, Colored grey image with 3 clusters
5.3 Comparison between Novel Framework and enhanced approach’s results

Comparison between both is evident from results above, however I will summarize it in a tabular form below.

5.3.1 Visual comparison of cluster mapping

Before heading towards statistical comparison on different images with Novel Framework and Enhanced Approach, I will show the difference in mapping between these two. Cluster mapping for experiment with Figure 5.2 and Figure 5.8 is shown as below, color legends are same as in Table 4.1.

![Figure 5.14 Cluster mapping comparison – Left: Novel Framework Approach, Right: Enhanced Approach](image)
In figure table, index represents clusters of greyscale image and column 1’s values represent corresponding mapped cluster of color image.

If we see the method proposed by Novel Framework[3], it says that for cluster 1 of grey image, we have to see it’s distances to 5 clusters of color image and have to choose the cluster with smallest distance, which is 3 in this case. Again for cluster 2 of grey image, we find that smallest distance is with cluster 3. So cluster 1 and 2 of grey image are mapped to cluster 3 of color image. Similarly, for cluster 3,4 and 5, minimum distance is with cluster 1 of color image, so cluster 3,4 and 5 are mapped to cluster 1 of color image.

This means that color information in cluster 2, 4 and 5 of color image is not used and is not transferred to grey image, which results in relatively poor color quality as compared to “Forced Mapping”.

It is also evident from cluster mapping table and visualization figures that Novel Framework leaves portions of un matched colors or atleast poorly colored, which is because of this mapping flaw.

### 5.3.2 Statistical comparison of cluster mapping

Clusters mapping method proposed by Novel Framework, is based on minimum euclidean distance of centre of cluster. Which results in mapping more than one clusters to single cluster, as described above. Following statistics prove this fact and show 100% mapping results with "Forced Mapping Algorithm".

<table>
<thead>
<tr>
<th>Image</th>
<th>Novel Framework Mapping</th>
<th>Forced Mapping</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total Clusters</td>
<td>Unmapped</td>
</tr>
<tr>
<td>Figure5.2,</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Figure5.8</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Figure5.3,</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Figure5.9</td>
<td></td>
<td>5</td>
</tr>
<tr>
<td>Figure5.4,</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Figure5.10</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Figure5.5,</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Figure5.11</td>
<td></td>
<td>3</td>
</tr>
</tbody>
</table>
Forced Mapping leaves no cluster unmapped, which helps to include maximum color information from reference image in color transfer process. Since “Forced Mapping” algorithm, excludes clusters mapped once, so this way all clusters are mapped to other image’s clusters making a one-to-one relation, meaning no loss of color information from reference image. Above Table shows that “Forced Mapping” algorithm gives 100% mapping which was not the case with Novel Framework method of cluster mapping.

### 5.3.2 Statistical comparison of color transfer

Since “Forced Mapping” ensures that all clusters from reference image are mapped to clusters of greyscale image, this also makes it possible to consider all colors from reference image as candidate for transfer to greyscale image.

#### Table 5.1 Statistical comparison of cluster mapping

<table>
<thead>
<tr>
<th>Figure5.6, Figure5.12</th>
<th>3</th>
<th>1</th>
<th>1 : 0.66</th>
<th>66%</th>
<th>0</th>
<th>1 : 1</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4</td>
<td>1</td>
<td>1 : 0.75</td>
<td>75%</td>
<td>0</td>
<td>1 : 1</td>
<td>100%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Figure5.7, Figure5.13</th>
<th>3</th>
<th>1</th>
<th>1 : 0.66</th>
<th>66%</th>
<th>0</th>
<th>1 : 1</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>5</td>
<td>3</td>
<td>1 : 0.4</td>
<td>40%</td>
<td>0</td>
<td>1 : 1</td>
<td>100%</td>
</tr>
</tbody>
</table>

#### Table 5.2 Statistical comparison of color transfer

<table>
<thead>
<tr>
<th>Image</th>
<th>Total Colors in Reference Image</th>
<th>Clusters</th>
<th>No of Colors Transferred</th>
<th>Transfer ratio</th>
<th>No of Colors Transferred</th>
<th>Transfer ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Figure5.2, Figure5.8</td>
<td>67220</td>
<td>3</td>
<td>31816</td>
<td>1 : 0.47</td>
<td>33473</td>
<td>1 : 0.49</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>30051</td>
<td>1 : 0.44</td>
<td>44642</td>
<td>1 : 0.66</td>
</tr>
<tr>
<td>Figure5.3, Figure5.9</td>
<td>24636</td>
<td>3</td>
<td>16187</td>
<td>1 : 0.65</td>
<td>20367</td>
<td>1 : 0.82</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>18085</td>
<td>1 : 0.73</td>
<td>22745</td>
<td>1 : 0.92</td>
</tr>
<tr>
<td>Figure5.4, Figure5.10</td>
<td>30609</td>
<td>2</td>
<td>23754</td>
<td>1 : 0.77</td>
<td>22771</td>
<td>1 : 0.74</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>21958</td>
<td>1 : 0.71</td>
<td>23367</td>
<td>1 : 0.76</td>
</tr>
<tr>
<td>Figure5.5, Figure5.11</td>
<td>21201</td>
<td>2</td>
<td>31883</td>
<td>1 : 1.50</td>
<td>31883</td>
<td>1 : 1.50</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>28890</td>
<td>1 : 1.36</td>
<td>34092</td>
<td>1 : 1.60</td>
</tr>
<tr>
<td>Figure5.6, Figure5.12</td>
<td>42965</td>
<td>3</td>
<td>36619</td>
<td>1 : 0.85</td>
<td>38508</td>
<td>1 : 0.89</td>
</tr>
<tr>
<td></td>
<td></td>
<td>4</td>
<td>36815</td>
<td>1 : 0.85</td>
<td>39132</td>
<td>1 : 0.91</td>
</tr>
<tr>
<td>Figure5.7, Figure5.13</td>
<td>45849</td>
<td>3</td>
<td>45493</td>
<td>1 : 0.99</td>
<td>45493</td>
<td>1 : 0.99</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td>32923</td>
<td>1 : 0.72</td>
<td>50906</td>
<td>1 : 1.10</td>
</tr>
</tbody>
</table>
These figures show that color transfer ratio with Enhanced Method is much better than Novel Framework. Transfer of colors on basis of Euclidean distance, avoids redundancy of colors in case of short cluster in reference image and avoids cutting of color information in case of bigger cluster size than reference image, which is not case with Novel Framework.

This transfer of colors decision on Euclidean distance also makes it possible to get grey image colored with textural and statistical feature property and not by imposing colors, which is in contrast with Novel Framework method of color transfer. Result statistics in above table show that color transfer ratio with Enhanced method is greater than that of Novel Framework, resulting in more colorful image.

Results obtained in Figure 5.5 and Figure 5.7 shows that there are more colors in resulting colored image than the original color image. This is due to introduction of $\alpha$ and $\beta$ to Luminance of grey image, which results in generation of new colors in resulting image. This also shows that the colors in grey image are approximated on basis of its luminance and they are not actually transferred from reference color image, since color in result image is generated by $\alpha$ and $\beta$ values of reference color image and L from grey image. These colors might be present in color reference image too but here they are generated by this process and not transferred.

5.3.3 Histogram comparison

Below is given histogram of Image colored by Novel Framework and by Enhanced method. This is histogram of image obtained in Figure 5.2 and Figure 5.8.

Histogram of Novel Framework shows that its levels start from origin, whereas the histogram of Enhanced method starts from 10 levels away from the origin. This means that one image is brighter than the other. Since histogram of image obtained by enhanced method is more away from origin than of obtained by Novel Framework, so it is brighter than that.

Similarly histogram of image obtained in Figure 5.7 and Figure 5.13 is shown below.
Figure 5.17 Histogram comparison-2

Histogram obtained by image colored by Novel Framework shows that it is more inclined towards origin as compared to histogram obtained by image colored by Enhanced method, so it is little darker than it. In other way, since histogram of image obtained by enhanced method is more away from origin than of obtained by Novel Framework, so it is brighter than it.

Both of these histograms show that for same image colored by Novel framework and Enhanced method, image obtained by enhanced method is more bright that that by Novel Framework. Reason for this brightness is inclusion of all clusters in color transfer process and decision of color on basis of feature vector distance. As I explained earlier that only $\alpha$ and $\beta$ values are transferred from color image to grey image and original L information of grey image is kept intact, since it is the only information available from grey image. Introduction of these $\alpha$ and $\beta$ values in grey image, results in generation of more color shades in resulting image. Since colors were transferred on basis of feature vector distance, and this decision was taken on equal or lower values of feature vector distance, this results in color generation with higher brightness and this is evident from histograms above.

5.3.4 Comparison conclusion

This enhanced method, uses all color information contained in reference image for making decision of color transfer. Forced Mapping makes it possible to avoid partial inclusion or exclusion of color information. Further decision of color selection on basis of Euclidean distance improves color selection by selecting colors with smallest Euclidean distance between pixels of mapped clusters.

Both of these enhancements make this method, of using reference image for approximation of colors, more powerful. Forcing all colors contained in a cluster to be transferred to mapped cluster, do not give approximation closer to reality, whereas not forcing all clusters to take part in color selection also do not give good results in terms of color transfer, since we will have limited number of colors to select. This enhancement solved these problems.
Further it also proves that, in case of Novel Framework method, even if we increase number of clusters, it doesn’t improve results for some images as in Figure 5.12 for 4 clusters, because the mapping refers clusters to clusters with minimum distance and it gives same results most of the time and sometimes even we get worse results as Figure 5.13 for 5 cluster shows. This statistical analysis clearly shows that this enhanced method provides with better, more vivid and colorful results as compared to Novel Framework method.

### 5.5 Comparison with Welsh et al. method

Since Welsh et al method is considered as base of techniques using color image for reference to colorize a grey image, so I am giving a comparison of results of my enhanced method with it. Images used are same as used by Welsh et al. in his paper and results of Welsh et al. method are also taken from his paper which is available at [3]. I am using same images because I have no implementation of that method for comparison.

---

![Figure 5.18 Comparison with Welsh et al. for Woods](image1)

Left to Right: Color image, Grey image, Colored grey image by Welsh et al method with 2 swatches, Colored grey image with 3 clusters

![Figure 5.19 Comparison with Welsh et al. for Nature](image2)

Left to Right: Color image, Grey image, Colored grey image by Welsh et al method with 3 swatches, Colored grey image with 4 clusters

![Figure 5.20 Comparison with Welsh et al. for Woods](image3)

Left to Right: Color image, Grey image, Colored grey image by Welsh et al method with global matching, Colored grey image with 3 clusters

Since, I don’t have statistical data for Welsh et al. method for his results published in [2], so instead of quantitative comparison, a subjective comparison can be made. This subjective comparison show that this enhanced method gives results closer to real than Welsh et al. method without use of swatches and human intervene. For example in Figure 5.20, color of
trees in grey image matches to color of grass in reference image, whereas with my enhanced method, color of trees in grey image matches with color of trees in reference image. Similarly, color shades of clouds in Figure 5.19 with enhanced method are smoother than Welsh et al. method. We see that this enhanced method gives good results without human intervene and human decision, which is a great success. In fact this task of selecting swatches is replaced with clustering performed over statistical and textural features.

5.6 Further findings

By performing number of tests with different images, I made few more observations.

While doing experiments about choosing reference image, I observed that a color image used for color information approximation should be chosen on base of type of texture of the grey image, beside expected colors in grey image.

While trying to find out number of clusters as input to this enhanced method, I get better results with number of texture types in grey image + 1 cluster. If we increase these clusters number by 1 or 2 clusters, results remain almost same. But if we decrease this number, results are not good.

While experimenting with HSV color space, it was observed that the output of coloring was not close to reality, this was because color channels in HSV are correlated with each other and when we add chromatic values of color pixel to V of grey image, color is changed because chromatic values of color pixels are related with V value of color pixel and changing this with V value of grey pixel generates different colors. So Lαβ is best suited for processes where decorrelation is essential.
Chapter 6

6.1 Conclusion

In this paper I presented an enhanced method for colorizing greyscale images. This enhanced method improves results significantly in terms of color approximation and distribution. This method is based on technique of using a reference color image for approximation and it uses textural and statistical features to find similarities between parts of color and grey images as proposed by Novel Framework. But unlike Novel Framework, this enhanced method uses Forced Mapping and Color Transfer on base of feature vector distance similarity. Forced mapping ensures that all colors in reference image are included in grey image and repetition or subtraction of colors is proportional to the feature vector distance.

This technique results an image which contains all colors from reference image, shades better and also avoids sharp boundaries in case of shades and gradient colors. Colored images by this technique have relatively smooth boundaries between clusters while keeping sharpness intact within cluster. Shine of objects in image is also closer to reality because of this proportional addition and subtraction of unequal number of pixels in mapped clusters.

Forced mapping ensures that two or more clusters should not map to one cluster, this means that no part of reference image will be in active in process of approximation of colors and as a result we see that problem of unreal and unmatched colors was solved.

In short, this enhanced method takes process of colorizing greyscale images to a new height of near-perfection and near-reality approximation. Only thing need to care is to select number of cluster carefully and choose reference image with desired colors only.

6.2 Future Work

Though this technique is most advanced in this category, yet it is not fully automated. Intervene for selecting number of clusters and choosing a reference image keeps it in category of semiautomatic technique. Color mapping also requires some future work for better matching. This can be avoided partially by using SOM [13] instead of k-means for clustering. So for future work, replacement of k-means with SOM is suggested. Further a neural network can also be introduced for cluster mapping and for repetition/subtraction of unequal number of pixels in mapped clusters.
References


[10] - Martin Oberholzer, Marc Östreicher, Heinz Christen and Marcel Brühlmann, Methods in quantitative image analysis http://www.springerlink.com/content/rj0462504n82g6wh/

