Radiometric restoration and segmentation of color images

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ABSTRACT

The task of object recognition involves classifying extracted objects, given a collection of extracted objects, each belonging to a predefined class. Inherently, object recognition from imagery is an ill-posed problem. Hence, additional behaviors or attributes of the extracted objects need to be incorporated in the analysis. In the case of color imageries, color information is one such attribute. To use the color information for the recognition, we should be able to properly extract the "unadulterated" color information, that is the information without the biases of the image-capturing device. Hence, that is where "color image restoration" comes into the picture. Color image restoration involves recovering color information that has been degraded during image formation. In other words, restoration purifies the adulterated color information. After initial stages of preprocessing, the next step towards recognition of objects is image segmentation. In this research, multilevel threshold and adaptive threshold techniques have been applied to color images in different color domains. The results have been tabulated and compared. This comparison is found to be very useful for selecting the suitable technique for the application at hand.

1. BACKGROUND

These days more and more image processing systems are being developed with color information as a vital component. This is because of vast amount of information embodied by colors, which is a rich resource for automated recognition systems. Besides this, human beings can discern thousands of color shades and intensities compared to only two-dozen shades of gray scale (Gonzalez, 1992). For proper handling of color images, fundamental make-up of colors needs to be understood well. Just like any other material, color has dimensions. Three dimensions are found to sufficiently describe color information. These are *hue*, *saturation*, and *intensity*. *Hue* distinguishes among colors such as red, green, purple etc. It is usually defined as the dominant wavelength in a spectrum (which is not always the case). Saturation (excitation purity) refers to how much the color is pure from a gray of equal intensity. The saturation of a colored light is defined as the proportion of pure light of the dominant wavelength and of white light needed to define the color. A completely pure color is one hundred percent saturated. Hence, saturation is expressed as either between zero and one or zero to one hundred percent. For example, Red is a 100% saturated color, whereas pink is 50% saturated red color. Intensity or lightness describes the achromatic notion of quantity of light or luminance. Brightness is another term used alternatively with lightness but it refers to actually perceived intensity from self-luminous bodies rather than from reflecting objects. During the past, different color models have been developed for a specification of color. They attempt to represent colors based on three primary colors in three-dimensional space. CIE spectral primary system, CIE XYZ system, CIE uniform chromacity scale, HIS, NTSC receiver primary system (RGN), NTSC transmission system (YIQ) are the prominent ones among the various coordinate systems. Most of the models are hardware-oriented. RGB model is used in color monitors and a broad class of color video cameras; the CMY (cyan, magenta, yellow which are secondary colors) model implemented in color printers; YIQ (luminance, inphase and quadrature corresponding to intensity, hue and saturation) model which is the standard for color TV broadcast. Transformation equations have been developed between coordinate systems (Jain, 1989).

1.1 Radiometric Restoration

Many books on image processing have a rigorous coverage of restoration techniques. Linear filtering method, restoration models and miscellaneous methods are explained in detail in these books. Readers who are interested to learn more about restoration techniques are encouraged to consult the books listed in the reference section. In this

research two methods are explored in depth i.e. point operators and linear algebraic methods. Point operators take gray level of a single pixel from input image and generate out gray level for the same pixel. Hence, point operators do not alter the spatial relationship between pixels in the image. The point operators define a mapping of input gray level to output gray level. Histogram equalization, histogram matching and contrast enhancements are some of the point operators, which are used in image enhancement techniques. Point operators can also be used for image restoration. Color balance is an ideal example of such technique. It involves balancing out radiometric output of image in different channels given an image with equal levels at different wavelengths like a white scene. The second method that is investigated in this research involves application of linear algebra principles for restoration. There are three major issues we have to deal with, regarding linear algebraic restoration technique. These are

- Designing the model
- Identifying the property of the system (linearity and shift invariance)
- Determining the radiometric impulse system response for linear and shift invariant systems.

The restoration technique can be modeled as linear system with the scene (exposure) as input and the image formed as an output with a certain linear function relating the two. This application of linear system theory is only possible if our image formation model is "linear and shift invariant". The big question is "Can the whole image formation process can be modeled as linear shift variant or invariant?" Unfortunately, not all of the physical phenomena involved in image formation are shift *invariant*. Some of them, like optical defocus and linear motion blur are spatially *invariant* whereas other lens distortions like astigmatism, coma, curvature of field, and rotary motion blur are spatially *variant*. Robbins and Huang have applied coordinate transformation technique to change the spatial variant functions to spatial invariant and then later transform back the image after performing restoration. (Robbins and Huang, 1972)

The success of any image restoration procedure depends on the accurate approximation of the impulse response of the image formation model, also referred to as the *Point Transfer Function* in some optics literatures. Many techniques have been developed during the past years. All the methods can be crudely categorized into two groups.

a) Using calibration targets
b) Using "analytically well formulated" input sources

Using calibration targets

This method involves extending the notion of geometric camera calibration to radiometric camera calibration. Images with known radiometric information, called "control images", are used for this purpose. These control images are composed of color patches of different wavelengths in the spectral range of the sensor. The calibration technique can be clearly depicted with the following diagram. Although the equation looks straight forward, there are many practical implementation issues that need to be considered.
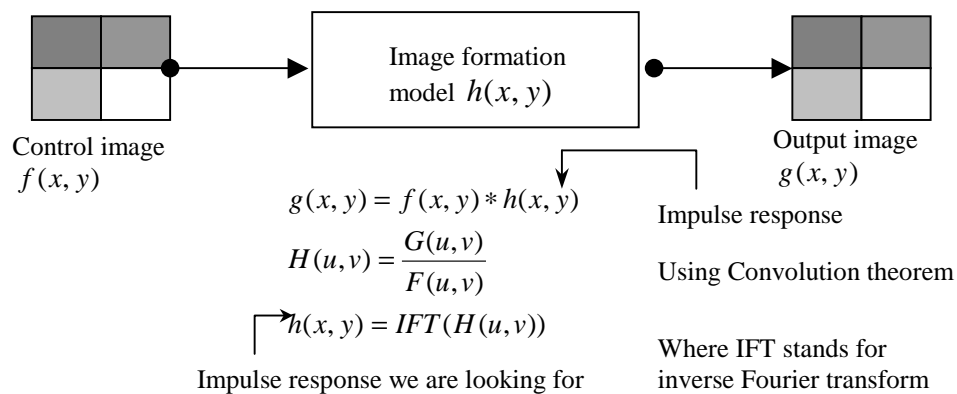
Control image
$f(x, y)$

Image formation model $h(x, y)$

Output image
$g(x, y)$

Impulse response

$$g(x, y) = f(x, y) * h(x, y)$$

$$H(u,v) = \frac{G(u,v)}{F(u,v)}$$

Using Convolution theorem

$$h(x, y) = IFT(H(u,v))$$

Impulse response we are looking for

Where IFT stands for inverse Fourier transform

Figure1. Impulse response determination using control images

Using "analytically well-formulated" input sources

The underlying principle in this method is that we calculate the impulse response by applying certain source signals to the system. These source signals are expected to output mathematically derivable and easy to measure and easy to apply inverse Fourier transforms. The commonly used signal sources are listed below with their expected output. (Castleman, 1996).

Sine wave targets $f(x,y) = \cos(2\pi s_o x)$	$g(x,y) = h(s_o,0)\cos(2\pi s_o x)$ $G(u,v) = H(s_o,0)\left[\delta(u-s_o) + \delta(u+s_o)\right]\delta(v)$	Repeat the procedure for different frequencies
Line targets $f(x,y) = \delta(x)$	$g(x,y) = \int_{-\infty}^{\infty} h(x,y)dy$ $G(u,v) = H(u,0)\delta(v)$	Repeat the procedure for different orientation
Edge targets $f(x,y) = u(x)$ $where \quad u(x) = \int_{-\infty}^{x}\delta(x)dx$	$g(x,y) = \int_{-\infty}^{\infty}\int_{-\infty}^{x} h(x,y)dy$ $G(u,v) = \dfrac{H(u,0)\delta(v)}{j2\pi u}$	Repeat the procedure for different orientation

Table 1. Analytically well-formulated input sources

The above signal sources were applied in many image restoration system. The direct observation of response of line targets is also called Line Spread Function (LSF) which is assumed to be a one-dimensional profile. Since most of natural scenes are composed of many linear features, this method can be easily applied. Profiles across bridges, roads, GPS van path could be used as one-dimensional profile. On the other hand, the Edge targets response is called an Edge Spread Function. It explains how an edge in the ground spread in the image. Subsequently, using edge gradient analysis method one can determine the line spread function. The other method involves direct observation of impulse given by the point source targets. The response to this type of input signal is called Point Spread Function. This method is difficult, as there is a requirement for precise identification of a sub-pixel target.

1.2 Segmentation

Segmentation decomposes an image into its constituent parts or subjects. This is the first step in image analysis. The level to subdivision depends on the problem to be solved. Traditional segmentation algorithms for monochrome are based on one of two basic properties of gray-level values: discontinuity and similarity. In the first property, it is to partition an image based on abrupt changes in gray level by detection of isolated points and detection of lines and edges in an image, such as edge-based segmentation. Edge-based segmentation is based on finding borders between components, thus exploiting inhomogeneities in the image. Edge-based segmentation relies on edges found in an image by edge detecting operators such as Canny, Sobel, Laplacian, and etc. However, Image resulting from edge detection cannot be used as a segmentation result because of incontinuity of edges although the method is easily adopted in various images. Supplementary processing steps must follow to combine edges into edge chains that correspond better with borders in the image. The most common problems of edge-based segmentation are an edge presence in locations where there is no borders and no edge presence where a real border exists. The principal approaches in the second property are based on homogeneity of intensity values within components, such as region growing segmentation. Region growing based on homogeneity of intensity values within components. Unlike gradient and Laplacian methods in edge-based segmentation, The region growing method finds regions directly hence the borders of regions found by region growing are perfectly thin and connected since the method only add pixels to the exterior of the region. The algorithm is also very stable with respect to noise.

In this research, we apply the region growing method to extract the stable color regions from an image after color restoration. The input domain of this research is a set of color terrestrial image taken by Mobil Mapping system (MMS).

2. METHODOLOGY

2.1 Restoration

In the background sections, the linear algebraic restoration has been discussed in the context of gray scale imagery. This method can easily be extended and applied to color images. To do this, the following procedures are suggested.

1) Performing point-operator restorations first.
2) Transform the RGB domain to HIS domain
3) Model the image formation as two-channel formation. At this stage, more attention should be given to illumination invariant dimensions of color, which are the hue and the saturation. This step assumes that subsequent analysis on the image is centered on illumination invariant parameters. Therefore, our image formation model should encompass the hue and saturation transformation. The big assumption here is that the saturation and hue transformation can be separated and modeled separately.

| Input Scene | → | **Hue Transformation** $h_h(x, y)$ | → | Output Scene |
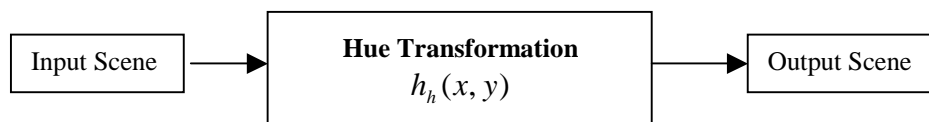
where $h_h(x, y)$ refers to the impulse response of the hue transformation.

| Input Scene | → | **Saturation Transformation** $h_s(x, y)$ | → | Output Scene |
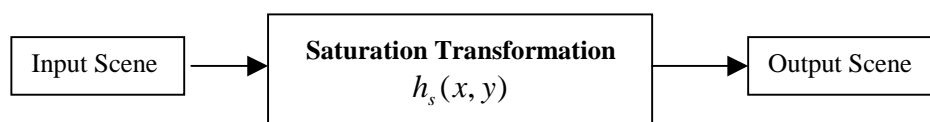
where $h_s(x, y)$ refers to the impulse response of the saturation transformation.

4) Apply the linear algebraic restoration method to the image once using impulse responses for saturation and once for hue.

2.2 Segmentation

Two types of segmentation have been explored in this research. The first one involves binarization of the image using thresholds. The binarization was conducted in the RGB and HIS domain. The thresholds are selected based upon a priori knowledge of the color information of the signs. Experiments were conducted to compare the results using three thresholds of R, G, and B and two thresholds of hue and saturation. Segmenting the image using hue and saturation without the intensity entails illumination invariant segmentation. The second method is the application of region growing method. The applied region growing method of this research is a *pixel aggregation*, which starts with a seed point and from that point grows regions by appending to each point those neighboring pixels that have similar properties such as gray level, texture, color and etc. However, The fundamental difficulties of region growing are selection of initial seeds that properly represent the interest regions and the selection of properties for including pixels during growing process. To handle the basic problems of region growing, this research suggests two strategies: adaptive threshold value and multi-band threshold values. The problem of selection of initial seeds is also solved by positions of interesting color pixels in an image after restoration. By restoration process, the image is changed into the stable and reliable color image. In H/S/I domain of color image, the hue values represent the color information of the pixel. From this hue domain of an image, the initial seed sets for interesting color can be obtained. Also the GPS/ISN information of MMS provides the proper range information for interesting area. To figure out the selection of threshold values to determine aggregation this research proposes an adaptive threshold strategy. The adaptive threshold method starts with small and proper threshold value to determine grouping of neighbor pixels and during the growing process the threshold value can be modified to reflect the properties of current grouped pixels for every predefined size. During growing, this method also updates the center gray value of the current region by updating the average gray value of current grouped pixels. This method applied on the three monochrome images (Red/Green/Blue or Hue/Saturation/Intensity) that are obtained by dividing one color image. The three bands are specific spectral images according to the each spectral bandwidth. For instance, the red band image is more reflected on red color of terrestrial scene. Therefore, this research suggests the multi-band region growing method to determine the aggregation of neighboring pixels. This method considers three values of three bands simultaneously during growing process. Each threshold value of three bands also should be weighted according to the colors to be extracted. For example, in case of extracting red regions, the green band is assigned to high weight value. A band image of the complementary color to be extracted obtains high priority since the complementary spectral reflectance of a specific color is less that of others. Hence, the boundary of the color region to be detected is clearly represented on the complementary band image. Therefore, Multi-band region growing by using suitable initial seed selection and adaptive threshold value generate extract color regions accurately. The total procedure of segmentation is as follows:

Input: Restored color image
- Divide a color image into R/G/B and H/S/I
- Pre-processing to generate initial seed set from Hue image
- Segmentation by region growing of multi-band images with adaptive threshold strategy.
    1. Picking a seed position from a seed set and add the seed pixel to candidate queue.
    2. Detach a candidate from candidate queue and aggregate into current region if aggregation condition is satisfied.
    3. Examine the neighboring pixels of current candidate pixel to aggregate into current region.
    4. If the property of neighboring pixels is satisfied within current threshold range, then add the satisfied neighboring pixels to the candidate queue.
    5. For every predefined size, update the threshold values according to the current region properties.
    6. Repeat the 2 ~ 5 until the candidate queue is empty.

Output: Segmented image

3. EXPERIMENTS AND RESULTS

As an illustration for region segmentation in color images, let us consider the following scenario.

Task: Segmentation of certain road signs from a sequence of images.

Considerations: Since this is an illustration for color image processing, we are going to use the color information as the distinguishing property (main attribute in the feature vector) for the recognition of road signs.

Procedures:
1. Perform radiometric restoration on all images (in this experiment only color balance was conducted).
2. Divide the color image into RGB and HIS components
3. Apply segmentation in both domains using the binarization or region growing technique
4. Apply post processing (point operators like median filter)
5. Record the results.

Results

1. Using binarization technique

Sequences of images were acquired using mobile mapping system GPSVan courtesy of TransMap PLC. The following results were recorded for the best threshold value from among numerous trials with different threshold and variances. The input image is one exposure from a GPSVan surveying data and the objective: to segment the "Do Not Enter sign"
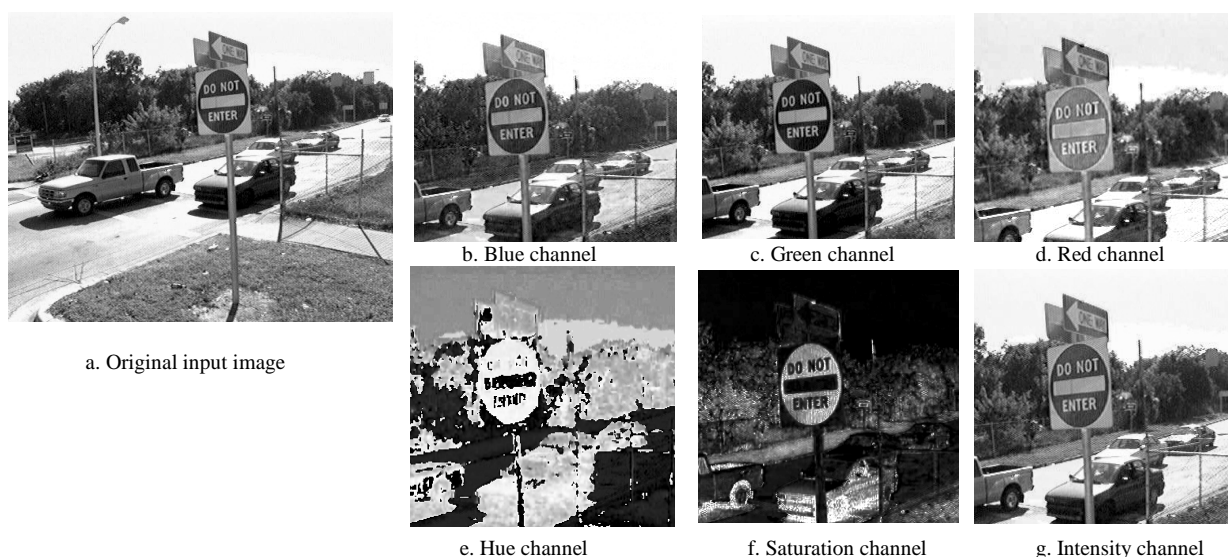

a. Original input image

b. Blue channel   c. Green channel   d. Red channel

e. Hue channel   f. Saturation channel   g. Intensity channel

Figure 2. Channels in different color coordinates

Result	H/S/I Domain Threshold and Variance			Result	R/G/B Domain Threshold and Variance		
	Hue	Saturation	Intensity		Red	Green	Blue
a	0630	0.260.3	70620	d	122610	32610	51610
b	0630	0.260.1	70610	e	122620	32620	51620
c	0615	0.260.3	1286128	f	100610	25610	51610

Table 2 Trial set for binarization in HIS domain and RGB domain

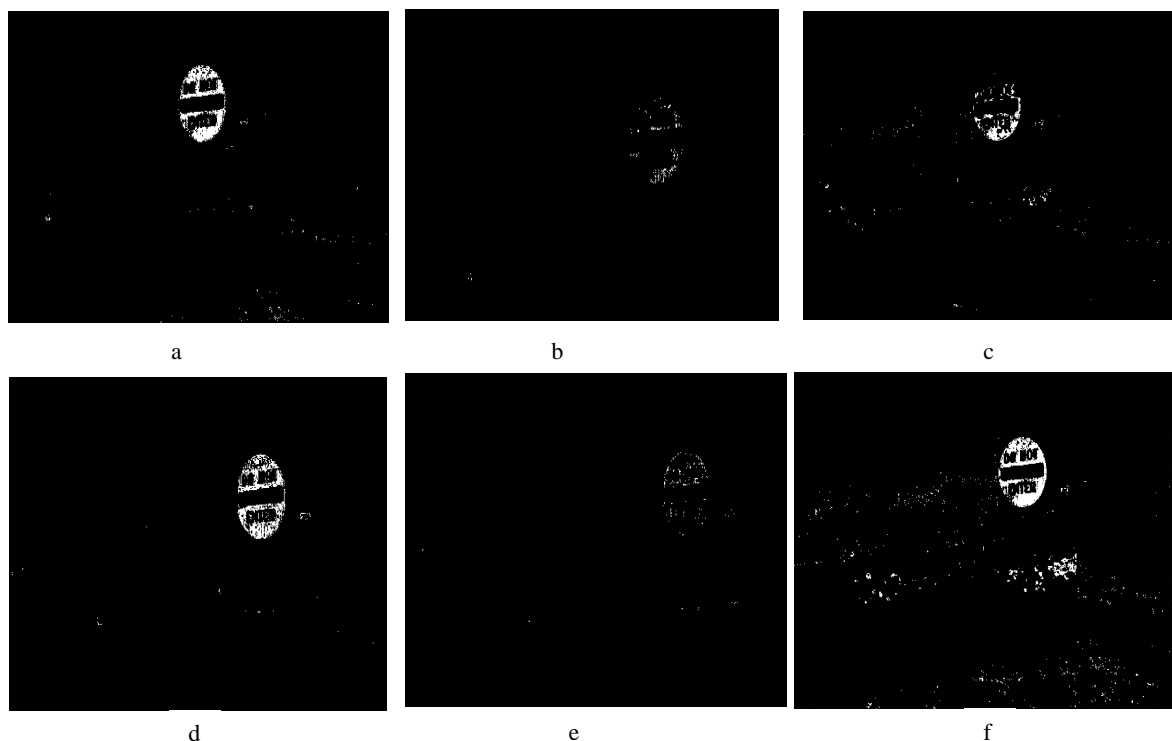
a

b

c

d

e

f

Figure 3. Output Result Using binarization technique

2. Region Growing technique

Table 4 shows the weighted values of RGB domain and HIS domain for experiment test. These values are applied to region growing algorithm in cases of before and after restoration.

Result	R/G/B Domain Weight Value			Result	H/S/I Domain Weight Value		
	Red	Green	Blue		Hue	Saturation	Intensity
a	0.5	0.3	0.2	d	0.5	0.3	0.2
b	0.3	0.5	0.2	e	0.3	0.5	0.2
c	0.3	0.2	0.5	f	0.3	0.2	0.5

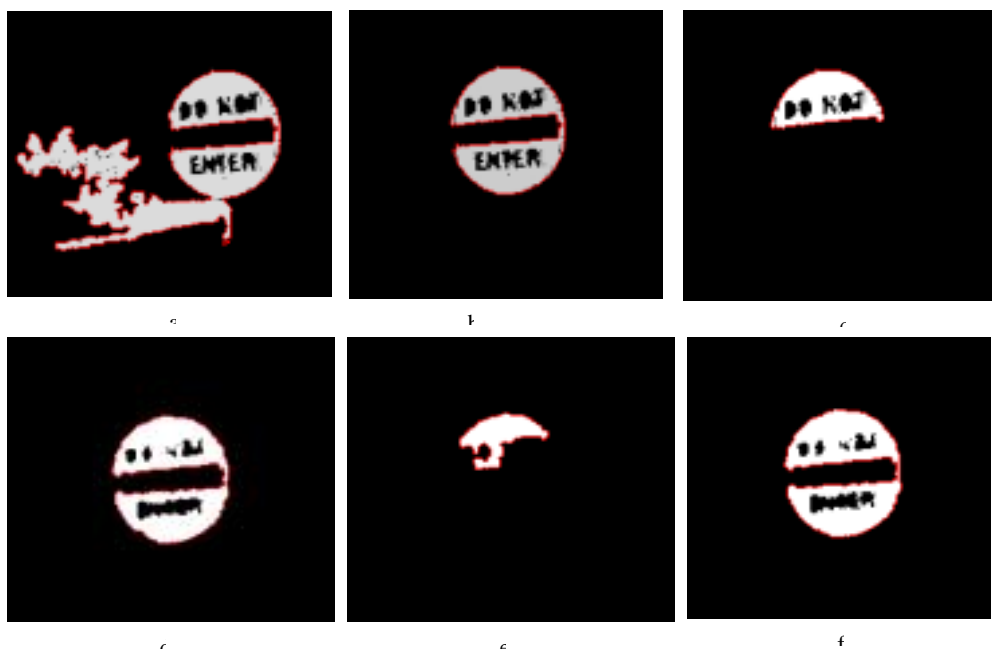Table 3. Seed point (84/425) adaptive threshold value = 35

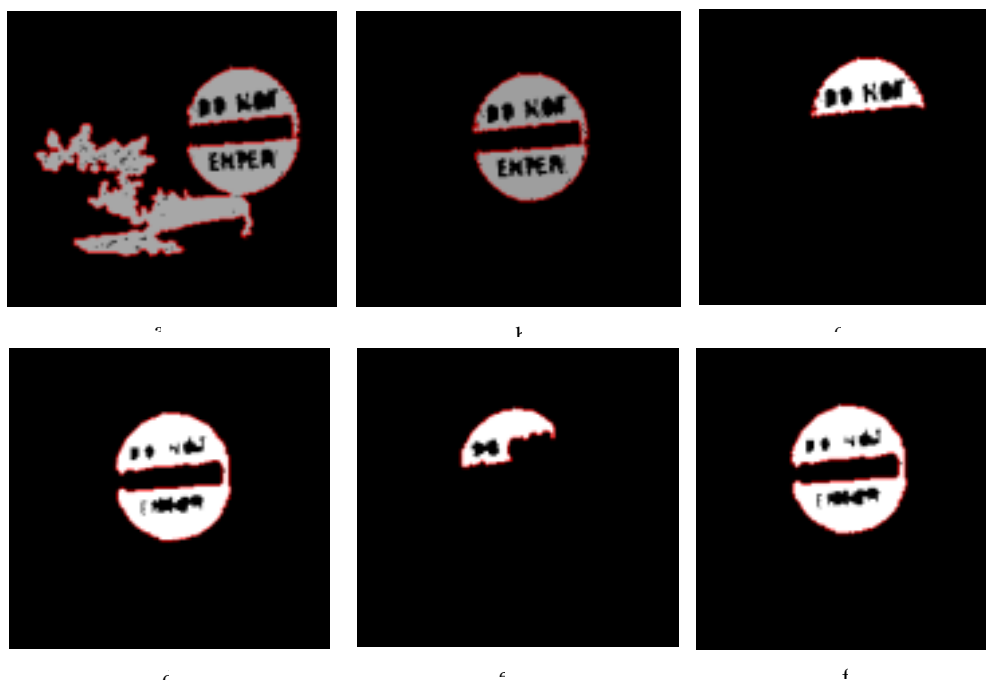Figure 4. Result of region growing before color restoration

Figure 5. Result of region growing after color restoration

4. REMARKS ON EMPIRICAL OBSERVATIONS

1. Color values with saturation closer to zero (diluted with lots of white) are basically gray scale values. Hence, balancing the colors is a good practical restoration method

2. The background influences color value of signs. For example, a white sign with its background the blue sky tends to have a bluish white behavior in its color, whereas a yellow sign with the background of a forest tends to have a greenish yellow behavior. This reflects that the gray value at a particular pixel is also affected by neighboring pixels. In other words, in our image analysis we can not give a one-to-one correspondence between the color value of the pixel with the color value of the object.

5. CONCLUSION AND FUTURE WORK

Segmentation of images is a topic that has been well pounded in many image-processing literatures. Most of these researches concentrate on segmentation techniques on gray scale imagery and RGB domain in the case of color images. In this research, it was demonstrated that the segmentation could be done in HIS domain too. In fact, this domain is found to be useful in decoupling color information from intensity, which is good news for illumination invariant segmentation systems.

Theoretical background for restoration technique has also been laid out. It has been pointed out that restoring the color information of the pixels plays an important role in subsequent image analysis tasks. Linear algebraic techniques were investigated for color image application.

The research is currently going on the algebraic methods of restoration. Experiments are to be conducted for determining the impulse response of the image formation using mathematically well formulated input signals. Linear algebraic restoration algorithms suggested in this paper will be tested and results recorded.

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