ENHANCEMENT OF DIGITAL COLOR HALFTONING PRINTED IMAGES

Edgardo FELIPE*, Mario RAMOS**
* Laboratory of Image Processing and Pattern Recognition,
Computing Research Center, National Polytechnic Institute, MEXICO
Institute of Cybernetics, Mathematics and Physics, Havana, CUBA
** Mexican Petroleum Institute
* edgardo@cic.ipn.mx, ** mramos@imp.mx

ABSTRACT

This paper presents an approach for enhancing digital color images printed in halftoning. Due to the repetitive nature of the process for image digitizing, and the common structure of patterns used to create halftoning in color images, it has been observed that the alterations of pixel colors, in general, are also repetitive. Based on the frequency of occurrence of pixels with a given color, and on the values of their RGB components, we have defined eight heuristic rules. We consider 'artifacts' those pixels with particularly altered values of their components having lesser frequency of occurrence. These rules then define as valid pixels those having a high frequency of occurrence, and as 'artifacts' those with low frequency of occurrence. The color of less frequent artifacts is then changed to some color of any more frequent valid pixel. This approach, based also on user defined essential colors, generates images that are notably enhanced. The method, which we call *Conditioned Selective Enhancement (CSE)*, has been applied with good results to the problem of enhancing several types of digital color images printed in halftoning.

KEY WORDS

Color Images Enhancement, Raster to Vector Conversion, Halftone Images, Color Halftone Image Digitizing, Artifacts Elimination.

1. INTRODUCTION

Color images are printed in halftone by using subtractive mixing CMY(K) of colors. To extract automatically the information of interest from these images, it is necessary to transform them to a digital format. When digitized, for example, with a conventional color flatbed scanner, numerous artifacts appear due to alterations to the RGB components of each pixel. The net result is that much of the original color of pixels is altered appreciably. If artifacts are not eliminated, it becomes difficult to analyze an image by computer, making it practically impossible to use the color to recognize and interpret color features and patterns in the image.

When digitizing color maps, the problem acquires a more serious connotation, because of the great variability of graphic information commonly incorporated into it. The main characteristics of digital color maps obtained in such form are described in [1] [2] [3] [4].

The use of conventional filters to clean uniform and impulsive noise in digital images is not effective in this case because of the increase in the number of colors, changes in the original colors, and loss of color information.

The main purpose of this work is to generate a final image with a minimum of artifacts, while preserving the basic structure of graphic patterns and retaining final colors same that are as close as possible to the original ones.

The experimental focus of this paper is the enhancement of digital color images of maps printed in color halftone, thereby allowing the automatic extraction of the color information contained in it, for subsequent incorporation into a Geographical Information System (GIS). The successful solution of this problem promises significant savings of money and time because the graphical information extracted from maps prepared a long time ago can be fused in a straightforward manner with data fed into the design of a new GIS [4].

The image used for our examples is a common color map of Mexico digitized to 300 dpi in a conventional flatbed scanner [7] from a printed paper on scholar atlas book [8].

THE PROBLEM

Figure 1 shows 11 x 11-pixel subimages of coconut palm and lemon symbols extracted from a map legend, and a 13 x 13-pixel letter 'a' extracted from the map itself. The coconut palm symbol has 33 colors and the lemon 31 colors, including the white background. The letter 'a' appears with 46 different colors. The dark control pixel on the right bottom corner does not affect in the analysis.

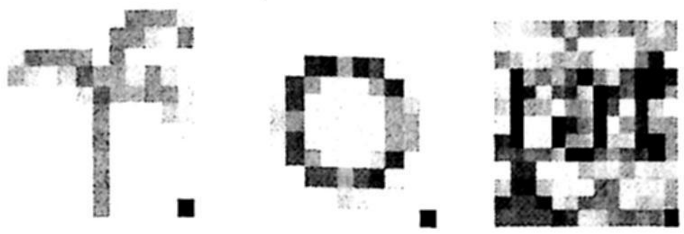
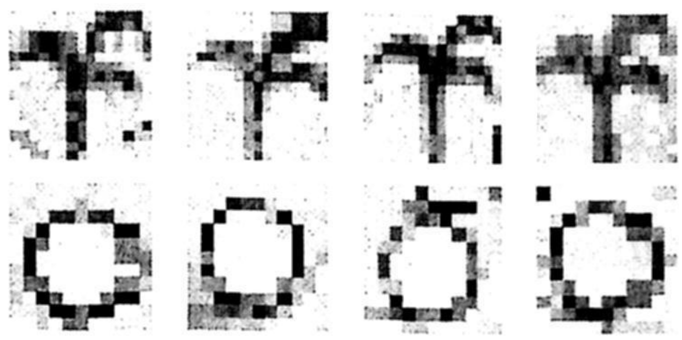


Figure 1. Symbols from a map of Mexico.

Figure 2 shows the same graphical symbols, but extracted now from the map itself (the coconut palm symbols are of size 15 x 15 pixels). The numbers of colors of each symbol are shown in Table 1. The presence of artifacts in all these images is evident.



1 2 3 4

Figure 2. Four versions of the same symbols extracted from the map.

Image	Size (pixels)	1	2	3	4
Coconut Palm	15 x 15	74	73	79	70
Lemon	11 x 11	54	39	41	43

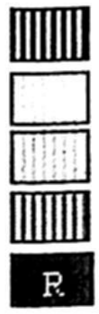
Table 1. Color number in images of Figure 2.

2. SELECTIVE CONDITIONED ENHANCEMENT

In the following analysis, where a halftone red dot R has been used, the following a priori considerations have been stated:

- Colors used for printing in subtractive mix CMY(K) are saturated. A red dot is created superimposing coincidently magenta and yellow dots.
- The register error is considered null
- Dot gain is null.
- The color of substrate is "white" and its distribution is uniform.

During the digitizing process, if sampling occurs exactly on the halftone dot, components of the pixel acquire correspondingly the hue of the dot, with brightness depending on the particular color (Figure 3). The remaining pixels acquire a color that depends on the percent of the samples over the halftone red dot and on the background color.



Pixels with background color
Red pixels 25% saturated
Red pixels 50% saturated
Red pixels 75-90% saturated
Red pixels 100% saturated

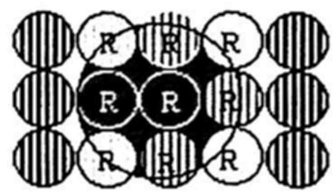


Figure 3. Sampling of a halftone red do t with arbitrary background color.

If the background color is white (Figure 4), which contains all colors, the corresponding color components (magenta and yellow) are relatively reduced, and the value of the other component (cyan) increases. As result, the dot color is less saturated, with the same hue, but brighter. If the pixel acquires less color from the red dot, its color appears whiter.

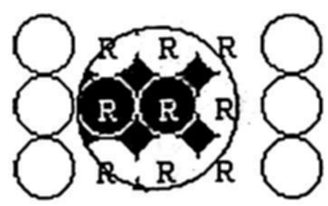


Figure 4. Sampling of a halftone red do t over a white background.

If the background color is black (Figure 5), which makes no color contribution, the corresponding color components (magenta and yellow) of the dot are also reduced, and the contribution to the other component is null. As result of this, the dot color acquires a shadowed color, with the same hue, but less saturated and less bright. If the pixel acquires less color from the red dot, its color appears blacker.

Figure 5. Sampling of a halftone red dot over a black background.

If the background color is other than white or black, and the color of a halftone dot is arbitrary with the area between dots is also being different, the variety of colors acquired by color components of pixels is higher. That is the reason why when digitizing a color halftone image pixels with many different colors appear, thus constituting 'artifact' that must be eliminated. When the frequency of sampling increases, the rate of 'artifact' pixels with respect to the total number of pixels in the image tends to diminish.

We consider as 'artifacts' those pixels with particular values of their components and lesser frequency of occurrence. A way to eliminate these pixels is to associate them with pixels of "legitimate" colors, whose components exhibit the characteristics of a set of eight heuristic rules detailed in Section 5. In this way, these pixels take the colors that initially should have been acquired by them when the image was digitized.

3. ESSENTIAL COLORS

In our approach, essential colors are those colors that will prevail in the final enhanced color image over the abnormal colors of 'artifact' pixels. They are those colors that appear in the legend and in backgrounds of the color map being enhanced. In spite of this, the user has the option to select the essential colors from the image he desires to enhance. Colors of 'artifacts' in the enhanced image are transformed to these essential colors, depending on the outcome of applying the 8 heuristic rules.

4. COLOR SAFE PALETTE

The Color Safe Palette (CSP) is a color palette that handles a limited number of colors. It has 216 colors, composed of only six possible R(ed), G(reen), and B(lue) values of each pixel in the image [6]. Possible values of each component are: 0, 51, 102, 153, 204 and 255. The resulting 216 colors are those obtained from the combination of these values.

When images are enhanced, the colors of pixel in the digital image are grouped into these 216 colors as a first alternative. In this task, three options are possible: Up, Down, and Middle. This means that the component values of each pixel are shifted to the next value in these three directions, that is, when Up (U), values are shifted to the immediately superior level, Down (D) to the immediately inferior level, and Middle (M), values are shifted Up and Down from the intermediate values of the CSP.

The Middle option is preferable in general because the alteration of transformed colors tends to be less than in the other two solutions, resulting in a higher subjective better quality. The grouping rules for the preceding approach are shown in Table 2.

5. BASIC PRINCIPLES TO DEVELOP THE HEURISTIC

The heuristic in the approach proposed was based on four basic principles:

1. Reduction of the final number of colors.
2. 'Artifacts' were considered those pixels having non-essential colors and lesser frequency of occurrence.
3. Due to the repetitive nature of both digitizing and color halftone printing processes, it was assumed that the enhancing process could be governed by strict rules created from experience and observation.
4. Color images do not have gray-level pixels, except white and black.

Color Group	Range of original component colors	Value of final component
1	$0 \le R, G, B \le 25$	0
2	$26 \le R, G, B \le 76$	51
3	$77 \le R, G, B \le 127$	102
4	$128 \le R, G, B \le 178$	153
5	$179 \le R, G, B \le 229$	204
6	$230 \le R, G, B \le 255$	255

Table 2. Grouping of image colors to the CSP colors (option M).

6. HEURISTIC RULES

Heuristic rules of the CSE approach are detailed in Table 3.

Rule number	Mutual relations of initial pixel components	Condition	Numeric examples	
			Pixels with RGB components	... will change their components to...
I	3D	2D' = 2D 1D' = 1D ± 51	255, 102, 153	255, 51, 153
II	(2I, 1D)	2I' = 2I; 1D' = 1D ± 51	153, 0, 153 153, 102, 153	153, 51, 153 (Excluding gray levels)
III	3I; 3D; (2I, 1D); (1I, 2D)	I, D ≤ 153	102, 51, 51 0, 51, 102) 153, 153, 153	0, 0, 0
IV	(2I, 1D)	$2I_e$' = 2I $1D_e$' = 1D ± 51	153, 102, 102	204, 102, 102 (Essential color)
V	(2I, 1D)	2I' = 2I ± 51 1D' = 1D	102, 204, 204	102, 153, 153
VI	(2I, 1D)	2I' = 2I ± 51 1D' = 1D ± 51	51, 102, 102	102, 153, 153 (Always + or always -)
VII	3D	1D' = 1D $1D_a$' = $1D_b$ $1D_b$' = $1D_a$	204, 51, 102	204, 102, 51
VIII	(2I, 1D)	2I' = 1D 1D' = 2I	153, 102, 102	102, 153, 153

Table 3. Heuristic Rules.

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Conventions for RGB components

C: Component of non-essential color;
C_e: Component of essential color;
C_a: Component of non-essential color A;
C_b: Component of non-essential color B;
Initially. I: Equal; D: Different;
Finally. I': Equal; D': Different.
Examples. 2I: two equal initial components;
$1D_e$': one different final component of essential color.
2I = 2I': it means that two equal initial components finally remain the same.

7. JUSTIFICATION OF THE ORDER OF RULES

The order given to heuristic rules is based on the following principles:

- In an ordered numeric list, elements with different components are more frequent than with any other combination.
- It is more likely that changes in component values occur in adjacent levels than in more distant levels.
- It is more likely that at the same time a single element varies than two or more elements.
- It is more likely that two (or more) elements change their component values in the same direction than in opposite direction.

8. ALGORITHM

Briefly, the algorithm is as follows:
Input: digital color halftone image, in BMP format.
Output: conditionally enhanced image, in BMP format.

```
{
 Input of digital image
 Determining image size
 Conversion of colors to the Color Safe Palette (CSP)
 Selection of essential colors from the image
    {
      Sequential scanning of image
      Control of RGB component of each pixel
      Ordering in a list from most to less frequent, pixel
      colors according to their frequency of occurrence,
    For the whole image, up there is not new grouping,
    execute the X rule, for 1 ≤ X ≤ 8
      {
       Grouping of pixels with rule X
       Reordering the list from more to less frequent
       colors
       Substitution in image color of pixels with new
       color defined by the rule X
       }
    }
}
```

9. RESULTS

The following results were obtained by using the algorithm described in the previous section. In all cases, only essential colors remained in the final image.

In order to compare results with the enhanced images in Figure 2, Figures 6-8 show the enhanced coconut palm image, but now including text. Similarly, Figures 9-11 show the enhanced lemon images.

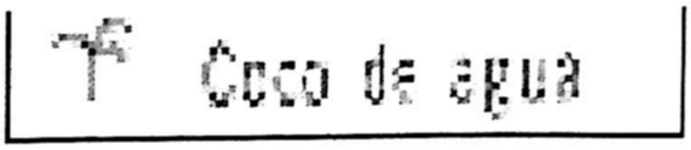


Figure 6. Original coconut palm extracted from the legend of map (63 colors).

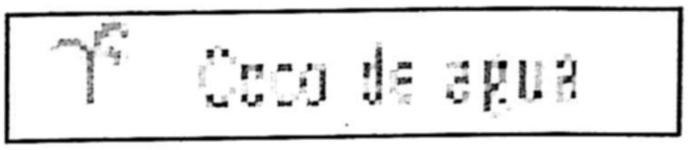


Figure 7. Image showing the coconut palm with CSP colors (11 colors).

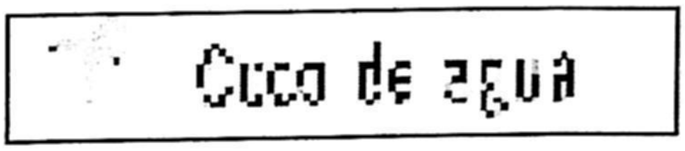


Figure 8. Enhanced coconut palm image (6 colors).

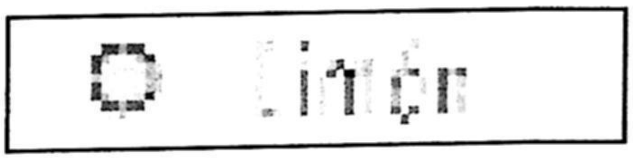


Figure 9. Original lemon extracted from the legend of map (58 colors.)

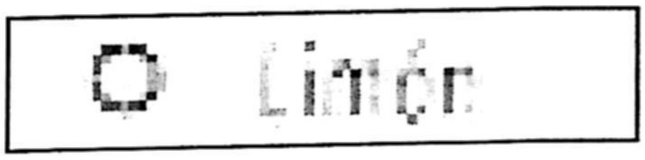


Figure 10. Image shown with CSP colors (21 colors).

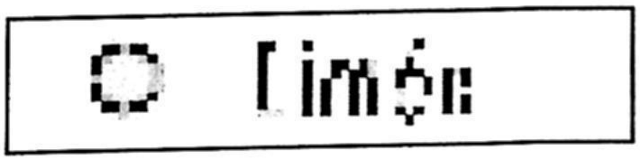


Figure 11. Enhanced lemon image (7 colors).

Figure 12 shows an 11x11 pixel image of the third letter 'a' from the text segment "Guanajuato" in the map. (a) Original, with 44 colors (b) CSP image with 20 colors, and (c) Enhanced image with only 4 (essential) colors.

A B C

Figure 12. Image of third letter 'a' from the text Guanajuato in the map: A, original, B, with CSP colo rs, C, selectively enhanced.

Figure 13 shows square images from the map of Mexico (with 251 001 pixels). They have 8 bit/pixel (256 colors): A, original; B, with CSP colors, and C, image selectively enhanced.

Figure 13. A. Original; B. With CSP colors; C. Image selectively enhanced.

Table 4 shows the total number of colors, number of essential colors, number of non-essential colors, and the percent of essential and non-essential colors for each image in Figure 13.

Image →	A	B	C
Total number of colors	256	42	11
Number of essential colors	0	11	11
Number of non-essential colors	256	30	0
% Of non-essential colors	100	71.4	0
% Of essential colors	0	28.6	100

Table 4. Total number of colors in each image and percent of essential and non-essential colors related to that number.

Table 5 shows the total number of pixels in the enhanced image of Figure 13C, the number of ungrouped pixels, and the percent of error, calculated on the basis of the total number of pixel not grouped with respect to the total number of pixel in the image. In both Tables 4 and 5, results are shown in shaded cells.

Image	1
Total number of pixels	251001
Number of pixels not grouped	0
% Of error to group	0

Table 5. Total number of pixels in imag e of Figure 13C and percent of error when grouped.

10. ERROR ANALYSIS OF THE METHOD

The error incurred by our new approach is calculated on the basis of the number of pixels with non-essential colors that were not grouped, with respect to the total number of pixels in the image, for those essential colors predefined by the user in the operation. On this basis, Table 5 shows, that the error in the selectively-enhanced image of Figure 13 is zero. To compare in some measure the enhanced quality of images, a part of the map legend was compared with a system being used to segment alphanumeric characters [12].

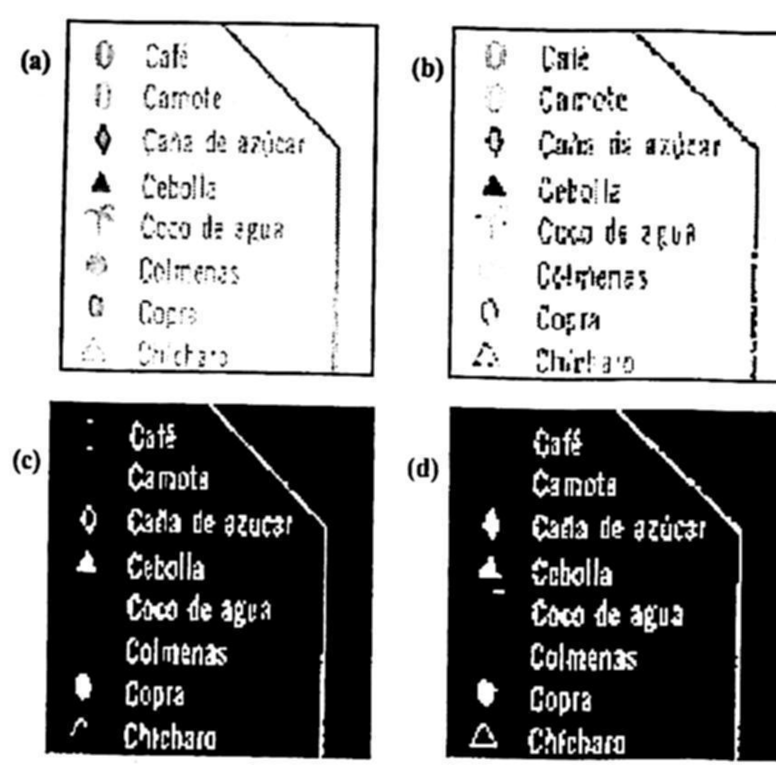


Figure 14. (a) Original Image (b) Enhan ced Image (c) Result after recognizing characters from the or iginal image (d) Result after recognizing characters from the enhanced image.

Table 6 details differences and Table 7 gives the final results. Total of characters properly segmented is (46 + 11)/60 x 100 = 95%; with the original image the result is (46 + 3)/60 = 81.67%. The general evaluation of results of the method can be seen more clearly in [9] [10].

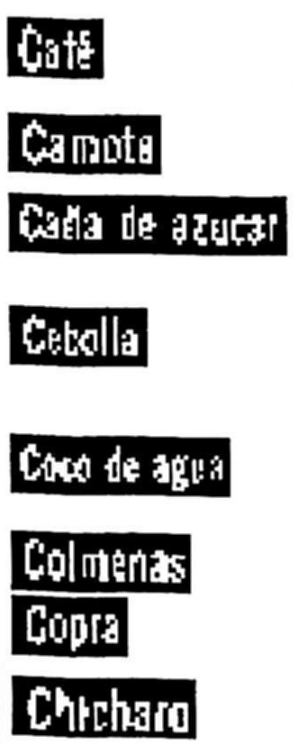
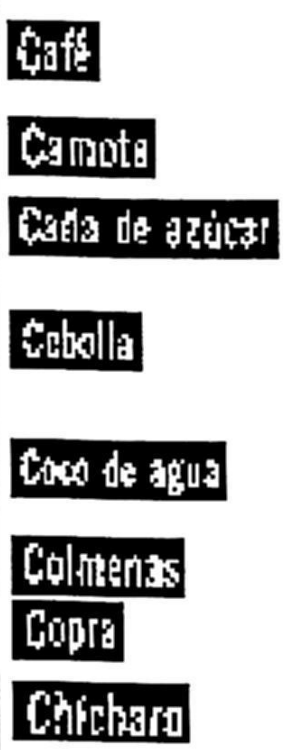
Characters from the map legend		
Segmentation from the original image Image (c)	Segmentation from the enhanced image (Image (d))	(Image (d) with respect to (c)
		Letter 't' is transformed to 'f'. Accent to letter 'e'. Letter 'a' loss quality Accent to letter 'u'. Split letter 'C'; 'e' is worst. Letter 'b' is completed. Letters 'u' and second 'a' were completed. 'm' is completed 'a' is improved. First 'h' is completed and 'i' is with dot.

Table 6. Comparing results from segmentation.

String	Character number	Enhanced	Poorer	Not change
Café	4	3 (a, f y é)	0	1 (C)
Camote	6	0	1 (a)	5 (c, m, o, t, e)
Caña de azúcar	12	1 (ú)	0	11 (C, a, ñ, a, d, e, a, z, c, a, r)
Cebolla	7	1 (b)	2 (C, e)	4 (o, l, l, a)
Coco de agua	10	2 (u, a)	0	8 (C, o, c, o, d, e, a, g)
Colmenas	8	1 (m)	0	7 (C, o, l, e, n, a, s)
Copra	5	1 (a)	0	4 (C, o, p, r)
Chícharo	8	2 (h, í)	0	6 (C, c, h, a, r, o)
8	60	11	3	46

Table 7. Final results.

11. ADVANTAGES AND DISADVANTAGES

Advantages of the new approach are the following:

1. The method does not require expensive drum scanners to digitize color maps printed in halftone, except when the size of image requires it.
2. Maps of very high quality and special conditions of conservation are not required.
3. It maintains the 4- and 8 pixels connectivity in point, linear and alphanumeric character symbols.
4. It is not required to know a priori any information about the particular shape, size, position, or real colors of graphical patterns in the map, except the colors to be selected as essential by the user.
5. The sampling frequency of the digitizing process, and the halftoning method used for printing are not important.
6. It can be used in any color image, even if it was not printed in halftone or captured by a specific type of digitizer.
7. Because it is a pixel-grouping method, it can be used in the segmentation of color images [11].
8. It does not require previous processing of images with classical 'blind' enhancing methods to previously eliminate uniform and impulsive noise.
9. Once the user has selected essential colors, the process requires only one run.

On the other hand, disadvantages of the method are the following:

1. It is not applicable to gray-level halftone digital images.
2. It causes a weak loss of information when the first grouping is carried out to the CSP colors.
3. By the nature of color halftone printing, colors in narrow parts of point, linear, and alphanumeric characters, sometimes are associated with the background color.
4. Some changes can take place in the original image colors, but generally these changes have little or no effect on the correct recognition of graphical patterns.

12. CONCLUSION

The algorithm of the conditional selective enhancement method fills a significant need for recognizing with higher reliability graphical patterns in digital color maps printed in halftone. The solution is based on the execution of eight heuristic rules that transform the altered color acquired by pixels when a color image printed in halftone is digitized. The transformation is based on essential colors defined by the user. Once the image has been enhanced, if the colors remaining in the image are only essentials, the total percent of error is zero. The number of pixels that do not undergo color transformation depends in general on the essential colors selected by the user.

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