Selective Conditional Enhancement of Digital Color Halftone Images
Mejoramiento Condicional Selectivo de Imágenes Digitales en Semitonos en Colores

Edgardo M. Felipe [a], Mario E. Ramos [b], Sergio Suarez [a] and Agustín F. Gutierrez [a]
[a] Center for Computing Research, National Polytechnic Institute, Mexico
`edgardo@cic.ipn.mx; ssuarez@cic.ipn.mx ; atornes@cic.ipn.mx`
[b] Mexican Petroleum Institute, Mexico.
`mramos@imp.mx`

Abstract
This paper presents an approach for enhancing digital color images printed in halftoning. The method, which we call Selective Conditional Enhancement, has been applied with good results to enhance digital color images printed in halftone. Due to the repetitive nature of the process for image digitizing and the common structure of patterns used to create halftone 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 of a given color, and on the values of their Red-Green-Blue (RGB) components, we have defined eight heuristic rules. In principle, these rules define as valid those pixels 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.
Keywords: Color enhancement, Scanned graphics enhancement, Raster to vector conversion, Enhancement of printed GIS images, De-halftoning.

Resumen
Este trabajo presenta un enfoque para el mejoramiento de imágenes digitales en colores impresas en semitonos. El método, al cual le hemos llamado Mejoramiento Selectivo Condicionado, ha sido aplicado con buenos resultados para mejorar las imágenes digitales en colores impresas en semitonos. Debido a la naturaleza repetitiva del proceso de digitalización de las imágenes y a la estructura común de los patrones usados para crear los semitonos en las imágenes en colores, se observó que las alteraciones de los colores de los pixeles, en general, son también repetitivas. Sobre la base de la frecuencia de ocurrencia de los pixeles de un color dado y de los valores de sus componentes Rojo-Verde-Azul (RGB), hemos definido ocho reglas heurísticas. En principio, estas reglas definen como válidos aquellos pixeles que tienen una alta frecuencia de ocurrencia, y como artefactos aquéllos con una baja frecuencia de ocurrencia. El color de los artefactos menos frecuentes es entonces cambiado a alguno de los colores de píxel válido más frecuente. Este enfoque, basado también en los colores esenciales definidos por el usuario, genera imágenes que son notablemente mejoradas.
Palabras clave: Mejoramiento del color; Mejoramiento de gráfica escaneada, Conversión de trama a vectores, Mejoramiento de imágenes de SIG impresas, Eliminación de semitonos.

1 Introduction

Color images are printed in halftone by using subtractive mixing in the Cyan-Magenta-Yellow-Black, CMY (K) color model. 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 in 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 that maps generally contain. The main characteristics of digital color maps obtained in such form are described in Levachkine-Polchkov (1999), Levachkine-Polchkov (2000), Felipe et al. (2000), Felipe et al. (2001), and Levachkine et al. (2002).

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 and pattern borders.

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

The image used for our examples is a common color map of Mexico digitized to 300 dpi using an HP PrecisionScan LTX conventional flatbed scanner (Figure 1). Its size is 854 x 521 (444 934 pixels), and 8 bits/pixel (256 colors). The source of the map was a scholar atlas book (Atlas NUTESA, 1979). All text in the image is in Spanish.
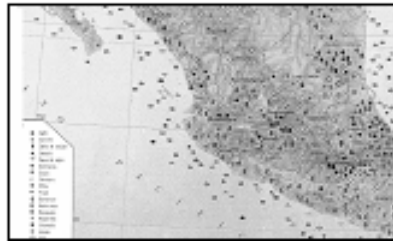

Fig. 1. Map from Mexico used as example

Figure 2 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, 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.

Fig. 2. Three graphical symbols from the map of Mexico

Figure 3 shows four versions of the same graphical symbols, but extracted now from the map itself (the coconut palm symbols are of size 15 x 15 pixels) showing the evident presence of artifacts. The numbers of colors of each symbol are shown in Table 1.
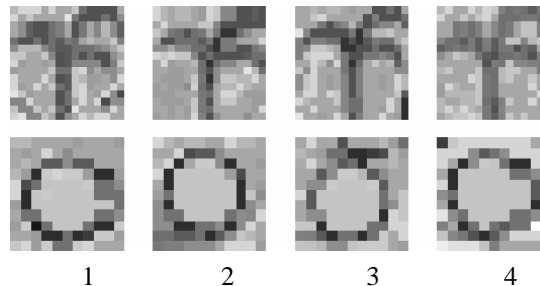

      1   2   3   4

Fig. 3. Four versions of the same symbols extracted from the map

Table 1. Color number in images of Figure 3

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

2 Background

The method for image enhancement described in Felipe et al., 2002a, which we named Selective Conditional Enhancement, is a new strategy for enhancing digital color halftone printed images. Based on the peculiarities of halftone printing, the method proposes a solution for selecting conditionally the final value to have by the RGB components of pixels.

Due to the repetitive character of the digitizing process and the patterns used for printing in halftone color images, it has been observed that the alteration of the color RGB components of pixel is also repetitive.

Depending on the rate that the colors of pixels appear in the digitized image and the values acquired by their RGB components, several heuristic rules have been defined. These rules consider valid only the pixels that appear with a high rate and as artifacts those which appear with a low rate. The rules change the color of artifacts to some of the colors appearing with a higher rate. This heuristic approach is based on experience and on the observation of how the color of pixels changes when the color halftone image is digitized.

This problem occurs, for example, when color cartographic maps printed in halftone are digitized in order to incorporate the information they contain to a Geographical Information System. Frequently, when digitized images are not enhanced, it is very difficult to recognize graphic and alphanumeric patterns present in the map, due to that the color cannot be used in the process of recognizing.

There are many digital methods for transforming to halftone the color images, namely (Murat-Vaidyanathan, 2001), Ordered Dither, Error Diffusion, the so-called Blue Noise Masks, Green Noise Halftone, Direct Binary Search, Dot Diffusion, Inverse Halftone and the Look-Up Tables – LUT. However, none of them guarantees a free-of-artifacts digital image when they are digitized.

In the literature, no method was found that is similar to the approach described in this paper to enhance the digital images obtained after digitizing color halftone printed images.

3 Common Problems When Digitizing Color Dots

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 and the dot gain are considered null
- The color of substrate is "white" (or "black") 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 4). The remaining pixels acquire a color that depends on the percent of the samples over the halftone red dot and on the background color.
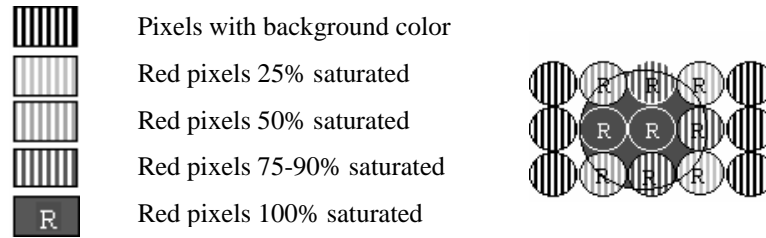
▥	Pixels with background color
▥	Red pixels 25% saturated
▥	Red pixels 50% saturated
▥	Red pixels 75-90% saturated
R	Red pixels 100% saturated

Fig. 4. Sampling of a halftone red dot with arbitrary background color

If the background color is white (Figure 5a), 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 sampled pixel acquires less color from the red dot, its color appears whiter.
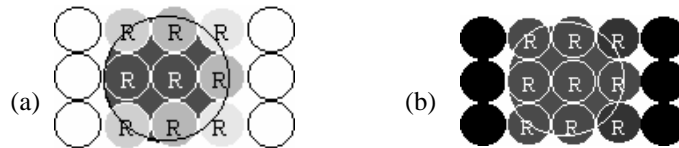
(a)   (b)

Fig. 5. Sampling of a halftone red dot over (a) a white background, (b) a black background

If the background color is black (Figure 5b), the corresponding color components (magenta and yellow) of the dot are relatively reduced, and the contribution to the other component (cyan) 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 darker.

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 the color components of pixels is higher. That is the reason why when digitizing a color halftone image pixels with many different colors appear as artifacts 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 also decrease.

We consider as artifacts those pixels with erroneous values of their components and lower 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 0. This way, these pixels take the colors that initially should have been acquired when the image was digitized.

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 RGB values of each pixel in the image (Weinman, L. WEB page). 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, following the nearest neighbor quantization principle. 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 (M) 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.

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

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

5 Essential Colors

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

6 Basic Principles and Rules

The heuristic in the approach proposed was based on four basic principles:
1. Reduction of the final number of colors.
2. Those pixels having non-essential colors and lesser frequency of occurrence were considered as artifacts.
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. The pixels can be associated only when the difference between the corresponding values of the RGB components is ±51 levels in the Color Safe Palette.

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 in 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.
- It is more likely changes in component values than in position.
- It is more likely that changes in component values occur, than changes in value and position at the same time.

7 Heuristic Rules

The three RGB components form an ordered list. Consider as primed the second value of the component to be compared, C_E as a pixel with essential color, C_J as a less frequent color and C_I as a more frequent color of a pixel. The eight heuristic rules can be described in the following way, each one illustrated with particular examples referred to one (or two) out of three components:

1. If the three RGB components of a color C_J are all different (R≠G≠B) but with respect to a color C_I any two out of three components are equal and the third one is different in ± 51 units (R´=R±51, G´=G, B´=B); or (R´=R, G´=G±51, B´=B); or (R´=R, G´=G, B´=B±51), then the color C_J will be associated to the corresponding most frequent color C_I.
    Example: Referred to the red component, pixel C_J with RGB components [153, 51, 102] will be associated to the most frequent C_I color with components [204, 51, 102] or [102, 51, 102], if any.

2. If a color C_J have two equal components and the third one is different (G=B; R≠G, B), or (R=B; G≠R, B), or (R=G; B≠R, G), if the different component differ in ±51 units with respect to a color C_I (R´=R±51; G´=G=B´=B); or (R´=R=B´=B; G´=G±51); or (R´=R=G´=G; B´=B±51), then the C_J color will be associated to the corresponding most frequent color C_I.
    Example: Referred to the blue component, pixel C_J with RGB components [102, 102, 204] will change to a C_I color with components [102, 102, 255] or [102, 102, 153], if any.

3. All color C_J with all three RGB components less or equal to level 102 (R, G, B≤102) and all pixels with gray levels with components less or equal to 153 (R=G=B≤153), will change its color to black (0, 0, 0).
    Examples: Pixel C_J with RGB components [102, 51, 51] will change to black color with components [0, 0, 0]; [51, 51, 51]→[0,0,0]; and so on.

4. If a color C_J have two equal components and the third one is different (G=B; R≠G, B), or (R=B; G≠R, B), or (R=G; B≠R, G) and if the different component differ in ±51 units with respect to a color C_E (G´=G$_E$=B´=B$_E$; R´=R$_E$±51); or (R´=R$_E$=B´=B$_E$; G´=G$_E$±51); or (R´=R$_E$=G´=G$_E$; B´=B$_E$±51), then the C_J color will be associated to a _nearest_ C_E color traveling up in the Ordering List.
    Example: Referred to the green component, pixel C_J with RGB components [255, 51, 255] will change to a nearest C_E color [255, 102, 255] or [255, 0, 255], if any.

5. If a color C_J have two equal components and the third one is different (G=B; R≠G, B), or (R=B; G≠R, B), or (R=G; B≠R, G), and if the two equal components differ in ±51 units with respect to a color C_I (R´=R, G´=G±51, B´=B±51); or (R´=R±51, G´=G, B´=B±51); or (R´=R±51, G´=G±51, B´=B), then the C_J color will be associated to the corresponding C_E color or to the most frequent color C_I, in this priority order.
    Example: Referred to the green and blue components, pixel C_J with RGB components [153, 51, 51] will change to the most frequent C_I color with components [153, 102, 102] or [153, 0, 0], if any.

6. If a color C_J have two equal components and the third one is different (G=B; R≠G, B), or (R=B; G≠R, B), or (R=G; B≠R, G), and if all three components differ in ±51 units with respect to a color C_I, the C_J color will be associated to the most frequent color C_I among the possibilities (R´=R±51, G´=G±51, B´=B±51).
    Example: Referred to the green and blue components, pixel C_J with RGB components [153, 51, 51] will change to the most frequent C_I color with components [204, 102, 102] or [102, 0, 0], if any.

7. If the three RGB components of a color C_J are all different (R≠G≠B) but any one out of three components are equal and the other two are inverted (R´=R, G´=B, B´=G); or (R´=B, G´=G, B´=R); or (R´=G, G´=R, B´=B) and if the three components differ in ±51 units with respect to a color C_I, then the C_J color will be associated to the most frequent color C_I.

Example: Referred to the green component, pixel C_J with components RGB equal to [153, 51, 102] will be associated to the most frequent C_I color [102, 51, 153].

8. If a color C_J have two equal components and the third one is different (R=G≠B), or (R=B≠G), or (B=G≠R), but their values are inverted (R´=G,B and G´,B´=R), or (G´=R,B and R´,B´=G), or (B´=R,G and R´,G´=B) with respect to a color C_I, then the C_J color will be associated to the most frequent color C_I.
Example: Between pixels C_J with RGB components [204, 51, 204] and [51, 204, 51], will prevail the most frequent one; it will associate the pixels of the other color.

- Rule 1 is included for the most likely case when only one RGB component changes value.
- Rule 2 is included for the following most likely case when two out of three RGB components are equal and the third different component changes value.
- Rule 3 is included to restore the black color and for contrast enhancement.
- Rule 4 associates the two great groupings carried out by rules II and I above with respect to the essential colors C_E.
- Rule 5 is included for the case when two equal RGB components change value.
- Rule 6 is included for the case when all three RGB components change value.
- Rule 7 is for the case when the three RGB components are different, one coincides and the other two RGB components change position.
- Rule 8 is for the case when two components are equal, the third one is different, and all three RGB components change value and position.
- Rules 6, 7, and 8 were created to guarantee that all pixels are grouped in the process.

8 Algorithm

Briefly described 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 by the user of essential colors from the image
    {
     Sequential scanning of image
    Control of RGB component of each pixel
 From most to less frequent, ordering in a list pixel colors according to their frequency of occurrence.
 For the whole image, up there is not new grouping, execute the X rule, for $1 \leq X \leq 8$
      {
   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 and Error Analysis of the Method

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

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

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

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

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

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

Fig. 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.
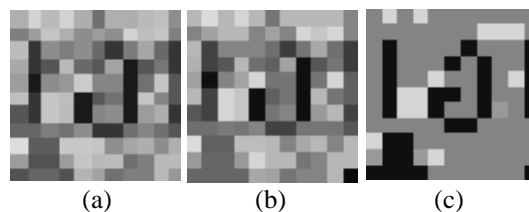

(a)   (b)   (c)

Fig. 12. Image of third letter 'a' from the text Guanajuato: (a) Original. (b) With CSP colors. (c) Selectively enhanced

Figure 13 shows square images from the map of Mexico of 502 x 502 with 252 004 pixels and 8 bit/pixel (256 colors).
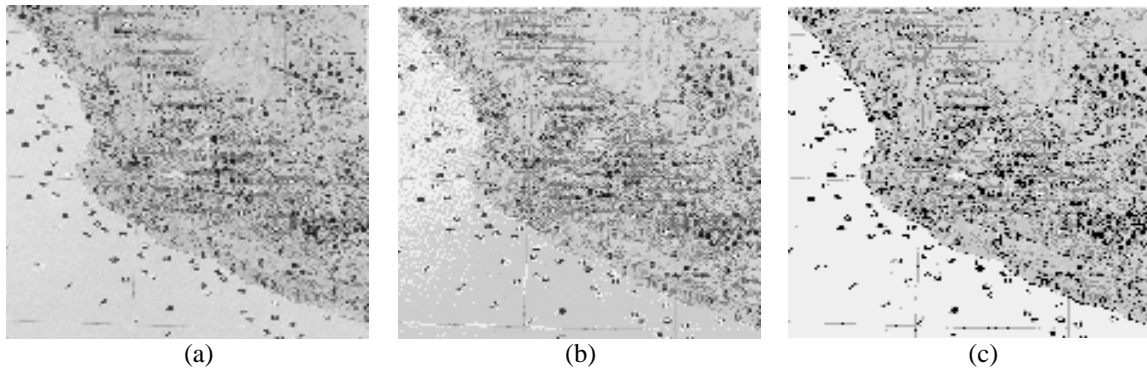

(a)   (b)   (c)

Fig. 13. (a) Original. (b) With CSP colors. (c) Image selectively enhanced

Table 3 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.

Table 3. Total number of colors in each image and percent of essential and non-essential colors

Image 13 →	a	b	c
Total number of colors	256	42	11
Number of essential colors	0	11	11
Number of non-essential colors	256	31	0
% of non-essential colors	100	73.8	0
% of essential colors	0	26.2	100

Table 4 shows the total number of pixels in the enhanced image of Figure 13(c), 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 3 and 4, results are shown in shaded cells.

Table 4. Total number of pixels in image of Figure 14(c) and percent of error when grouped

Image	13c
Total number of pixels	252004
Number of pixels not grouped	0
% of error to group	0

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 4 shows, that the error (pixels not grouped) 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 shown in Figure 14 (a) was compared with a system being used to segment alphanumeric characters (Velazquez et al., 2001).
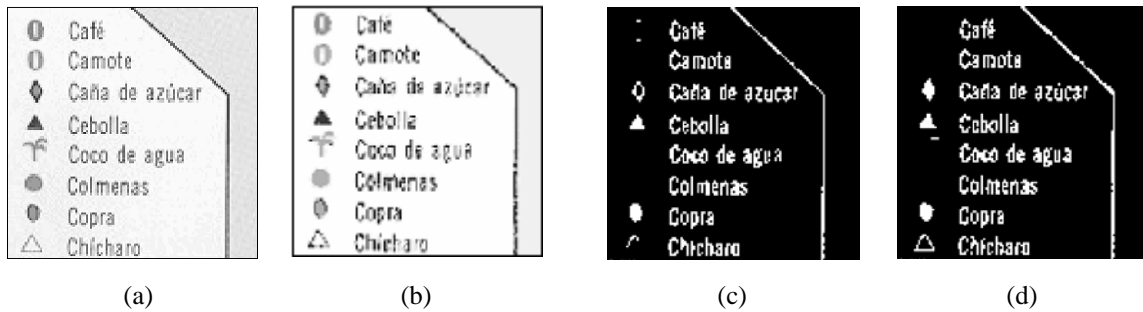
(a)   (b)   (c)   (d)

Fig. 14. (a) Original Image. (b) Enhanced Image. (c) Result after recognizing characters from the original image
(d) Result after recognizing characters from the enhanced image

Table 5 details differences and Table 6 gives the final results. The total percentage of characters properly segmented was (46 + 11)/60 x 100 = 95%; in the original image the result was (46 + 3)/60 = 81.67%. The general evaluation of results of the method can be seen more clearly in Felipe et al. 2002a, and Felipe et al. 2002b.

Table 5. Comparing results from segmentation

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)**
Café	Café	Letter 't' is transformed to 'f'. Accent to letter 'e'.
Camota	Camota	Letter 'a' loss quality
Caña de azucar	Caña de azúcar	Accent to letter 'u'.
Cebolla	Cebolla	Split letter 'C'; 'e' is worst. Letter 'b' is completed.
Coco de agua	Coco de agua	Letters 'u' and second 'a' were completed.
Colmenas	Colmenas	'm' is completed
Copra	Copra	'a' is improved.
Chicharo	Chicharo	First 'h' is completed and 'i' is with dot.

Table 6. Final results

String	Character number	Enhanced	Poorer	Not changed
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,
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)
	8	2 (h, í)	0	6 (C, c, h, a, r, o)
8	60	11	3	46

10 Advantages and Disadvantages of the CSE Method

The 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 the paper requires it.
2. Maps of a very high quality and special conditions of conservation are not required.
3. It maintains the 4- and 8-connectivity of pixels in lines 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 the 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 (Felipe et al., 2002c).
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, several 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, lines, 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.

11 Conclusion

The algorithm of the selective conditional enhancement method fills a significant need for recognizing with higher reliability graphical patterns in scanned 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 halftone image is digitized. In

principle, these rules define as valid those pixels having a high frequency of occurrence and as artifacts those with low frequency of occurrence. The final pixel color is based on essential colors defined by the user. 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. Once the image has been enhanced, if the colors remaining in the image are only essentials, the total percent of error is generally lower than 0.1%. The number of pixels that do not undergo color transformation depends in general on the essential colors selected interactively by the user.

Acknowledgments

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Edgardo Manuel Felipe Riverón. *He received the B.Sc. degree in Electrical Engineering from the Higher Polytechnic Institute Jose Antonio Echeverria, in Havana, Cuba, in 1967. He received the Ph.D. degree in Technical Sciences from the Computer and Automation Research Institute, in Budapest, Hungary, in 1977. He is currently Full Professor and Senior Researcher at the Center for Computing Research of the National Polytechnic Institute of Mexico. His research interests are on Image Processing and Analysis, Computer Vision and Pattern Recognition, in particular color quantization, retina analysis, biometric solutions, document analysis and mathematical morphology applications.*

Mario Eduardo Ramos Garcia. *He received the B. Sc. in Computer Systems Programming from the Technological Institute of Celaya in 1990, and the M. Sc. degree from the Center from Computing Research of the National Polytechnic Institute of Mexico, in 2002. Currently he works in Software Engineering and Information Systems at the Mexican Petroleum Institute. He has experience in Distributed Systems, Graphical Computing in Supercomputers, Computer Center Management, Electronic publication of documents, WAN, MAN, and LAN Networks and Informatics Security.*

Sergio Suarez Guerra. *He received his B. Sc. in Electrical Engineering in the Superior Polytechnic Institute Jose Antonio Echeverria, Havana, Cuba, in 1972, and his Ph.D. degree in the Academic of Sciences of the Soviet Union, Moscow, in 1979. Since 1998 he is Full Professor and Senior Researcher at the National Polytechnic Institute, Mexico. Areas of interests are Digital Signal Processing, Speech Processing and Speech Recognition.*

Agustin Francisco Gutierrez Tornes. *He received the B.Sc. degree in Economics from the Institute of Economics from the University of Havana, Cuba, in 1970, and his Ph. D. degree from the Enterprise Improvement Research Center, Agricultural Academy (SGGW-AR), Warsaw, Poland, in 1984. Actually as a Systems Coordinator at Banamex, S.A. (CITIGROUP) and as an Adjoin Professor at the Instituto Tecnológico y de Estudios Superiores de Monterrey. His research interests are on different topics of Software Engineering.*