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SEGMENTATION OF SCANNED MAPS IN UNIFORM COLOR SPACES

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ABSTRACT

An important aspect of GIS operation is acquisition of spatial data from different types of maps. In principal, this may be done using image processing techniques. Especially for color printed topographic maps, a powerful segmentation algorithm is needed to separate the information layers.

In this paper, a new color segmentation algorithm is presented, which is based on the uniform CIE-L*u*v* color space and its u'v' color table. Main advantages of the new technique are very clean segmentation results with smooth borders in particular in case of color-mixed region outlines of scanned full-color map prints. This property is very important to support subsequent vectorization and interpretation steps.

INTRODUCTION

During the last years, geographic information systems (GIS) have become very powerful tools for processing, storing, and organizing spatial data. Acquisition of necessary spatial data is one of the most important aspects on the way to sensible system operation. In many cases, data is only available in form of a color printed, paper-based maps (e.g. topographic maps), which often have to be digitized manually.

To raise system efficiency and speedup database creation, methods for automatic and semi-automatic digitization have been developed. The vectorization and map analysis techniques for scanned line-art maps (black and white) have reached a high standard and are available as commercial software tools [Suzu1990] [Maye1992], but analysis of colored maps is still a field of intensive research. A system for automatic analysis of complex colored topographic maps is described in [Ebi1994], [Laut1992]. An essential part of such a system is an efficient method for segmentation of color-scanned maps. As segmentation is a principle system component of map analysis, a very high quality of its results is necessary to allow sensible processing. The presented algorithm, which is based on the uniform CIE-L*u*v* color space and its u'v' color table, fulfils this condition [Laut1993]. The algorithm itself is not applicable for any kind of color image segmentation but was optimized especially for processing of scanned printed color documents (e.g. maps).

COLOR SPACES

Color spaces used for image processing purposes should have color discrimination properties which are comparable to those of the human visual system. In an ideal color space, numeric difference between two stimuli should be proportional to difference noticed by human perception. Another important property, especially for operations on a local neighbourhood is validity of additive color mixture laws. Uniform CIE-L*u*v* color space fulfils these requirements and may be implemented without needing too much computing time.

TRANSFORMATION OF SCANNER RGB-DATA INTO U'V' COLOR TABLE COORDINATES

Map image data is produced by a color scanner as 8-bit color values in an uncalibrated RGB color system. To transform this data into the uniform L*u*v* color space, color correction has to be applied. This may be done in three steps:

1) Transformation from RGB into XYZ tristimulus color values,
2) Color correction using standardized color plates,
3) Transformation of corrected XYZ tristimuli into u'v' color coordinates of CIE-L*u*v* color space.

Transformation RGB to XYZ tristimuli: Tristimulus values produced by a desktop-scanner do normally not have a defined relation to a standardized color system. If the primary colors of the optoelectronical system of the scanner are known, tristimulus values of an image may be transformed into a standardized color coordinate system. A sensible system is the internationally applied XYZ-system of CIE [CIE1986].

For calculation of scanner primaries, properties of the system components have to be known:

- spectral distribution of power of scanner illuminant,
- spectral transmittance of R, G, an B color filters,
- spectral sensitivity of scanner sensor (e.g. CCD).

Taking into account the properties of all components, the behaviour of the complete system and the primaries X_F, Y_F and Z_F may be calculated as

$$X_F = \frac{1}{k}\int_K^L \varphi_\lambda \cdot \bar{x}(\lambda)\,d\lambda;\quad Y_F = \frac{1}{k}\int_K^L \varphi_\lambda \cdot \bar{y}(\lambda)\,d\lambda;\quad Z_F = \frac{1}{k}\int_K^L \varphi_\lambda \cdot \bar{z}(\lambda)\,d\lambda.$$

Integral limits are given by the lowest and highest wavelength of the visible spectrum. φ_λ is determined from sensor transmission function $\tau_S(\lambda)$, filter transmission $\tau_F(\lambda)$ and spectral distribution of power of scanner illuminant S_λ: $\varphi_\lambda = S_\lambda \cdot \tau_S(\lambda) \cdot \tau_F(\lambda)$.

The scaling factor k causes the primary Y=100 for an ideal white object. Thus, k may be calculated as

$$k = \frac{1}{100}\int_K^L S_\lambda \cdot \bar{y}(\lambda)\,d\lambda.$$

Transformation of scanner data is done using a linear equation system. Color stimuli X, Y, Z are determined from scanner primaries X_n, Y_n, Z_n and scaled pixel values of RGB scanner channels:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} X_R & X_G & X_B \\ Y_R & Y_G & Y_B \\ Z_R & Z_G & Z_B \end{pmatrix} \cdot \begin{pmatrix} R/255 \\ G/255 \\ B/255 \end{pmatrix}$$

Color correction of standardized stimuli XYZ: Standardized color stimuli XYZ may now be corrected. Due to incomplete known scanner parameters, correction rule may not be calculated directly but has to be derived from measured behaviour of the scanner system on standardized color plates (we used 22 NCS color plates [SS019100]).

The three-dimensional color correction method was adapted from a two-dimensional image registration technique, which is mainly used in remote sensing image processing [Rich1986]. A XYZ color tristimulus will be mapped to a new tristimulus X'Y'Z' by applying first or second order mapping polynomials. Polynomial factors may be calculated from.

$$\mathbf{x} = \mathbf{F} \cdot \mathbf{a}, \quad \mathbf{y} = \mathbf{F} \cdot \mathbf{b} \quad \text{und} \quad \mathbf{z} = \mathbf{F} \cdot \mathbf{c},$$

where x, y, z are the vectors representing the tristimuli of the standardized color plates, a, b, c are the vectors giving the correction coefficients and F is a matrix resulting from the calculated tristimuli of the scanned color plates.

Transformation of XYZ tristimuli into u'v' chromaticity diagram: u' and v' chromaticity coordinates may be derived from the color corrected XYZ tristimuli using the equations [MacA1985]

$$u' = \frac{4 \cdot X}{X + 15 \cdot Y + 3 \cdot Z} \quad \text{and} \quad v' = \frac{9 \cdot Y}{X + 15 \cdot Y + 3 \cdot Z}.$$

Combination of transformation steps: All three transformation steps (RGB-XYZ, color correction, and XYZ-u'v') may be integrated into two equations. Based on the characteristics of the color channels of the used scanner (Optoscan 2000), following equations have been derived:

$$u' = \frac{(0{,}6964 \cdot R + 0{,}462 \cdot G + 0{,}1812 \cdot B)}{(1{,}3531 \cdot R + 4{,}2294 \cdot G + 1{,}1052 \cdot B)} \quad \text{and}$$

$$v' = \frac{(0{,}7308 \cdot R + 2{,}4336 \cdot G - 0{,}072 \cdot B)}{(1{,}3531 \cdot R + 4{,}2294 \cdot G + 1{,}1052 \cdot B)}.$$

In both equations, numerator and denominator may be calculated by three table look-ups and two additions using the scanner pixel values as index.

SEGMENTATION OF COLOR LAYERS

Several segmentation techniques published during the last years have disadvantages like non uniform color spaces [Andr1990], non additive color spaces [Cele1990] or necessity of definition of basic parameters (e.g. number of clusters) [Bala1991]. The new segmentation method for colored map images does not have these drawbacks. Important benefits are:

- automatic determination of cluster number and cluster center positions,
- consideration of additive color mixtures (mixels),
- colors of low frequency will not be suppressed during clustering,
- scattered color areas will not be subdivided into an unnecessary number of clusters.

The presented segmentation technique is not a universal method for color image segmentation but was optimized for processing of images of color printed topographic maps. For this special task, only gray colors have to be segmented considering their luminance. All other colors have just to be separated by their chromaticity. The algorithm may be divided into four steps:

- detection of maxima (cluster centers) and ridges (additive color mixture) in the two-dimensional histogram of the u'v' chromaticity diagram,
- image segmentation using pixel chromaticity coordinates as criteria under consideration of the additive color mixture laws,
- segmentation of the gray colored cluster using the pixel luminance,
- correction of errors in separated color layers.

Detection of maxima and ridges in u'v' histogram: The technique for detection of maxima in 1D-histograms [Seza1990] has been extended to two dimensions. 2D-CDF (cumulative distribution function) $s(u'_q, v'_q)$ equals to

$$s(u'_q, v'_q) = \sum_{i=0}^{u'_q} \sum_{j=0}^{v'_q} h(i,j).$$

Two-dimensional maxima detection signal $r_N(u'_q, v'_q)$ may be obtained as difference between CDF $s(u'_q, v'_q)$ and mean value of its local NxN neighbourhood:

$$r_N(u'_q, v'_q) = s(u'_q, v'_q) - \frac{1}{N^2} \cdot \sum_{i=u'_q - \frac{q \cdot N}{2}}^{u'_q + \frac{q \cdot N}{2}} \sum_{j=v'_q - \frac{q \cdot N}{2}}^{v'_q + \frac{q \cdot N}{2}} s(i,j).$$

The size N (which should be an odd number) of the neighbourhood is uncritical. A value of 1/4th of the greater length of a side of the populated histogram area showed to be sensible. Considering the function $r_N(u'_q, v'_q)$ maxima may be detected as:

$$f(r_N(u'_q, v'_q)) = \begin{cases} 1 & \text{if } (r_N(u'_q, v'_q) \geq 0) \wedge (r_N(u'_q, v'_q - q) < 0) \wedge \\ & \quad (r_N(u'_q - q, v'_q) < 0) \wedge (r_N(u'_q - q, v'_q - q) < 0). \\ 0 & \text{otherwise} \end{cases}$$

If $f(r_N(u'_q, v'_q))$=1, histogram entry represents a maximum.

For detection of ridge point, which may be regarded as histogram maxima on only one axis, 2D-CDF $s(u'_q, v'_q)$ has to be replaced by a modified function $s'(u'_q, v'_q)$ which is calculated as product of 1D-CDFs of each histogram row s'_v and column s'_u:

$$s'_u(u'_q, j) = \sum_{j=0}^{u'_q} h(i,j) \text{ and } s'_v(i, v'_q) = \sum_{i=0}^{v'_q} h(i,j).$$

i and j are representing the column and row in the histogram. Modified CDF may be obtained as:

$$s'(u'_q, v'_q) = s'_u(u'_q, v'_q) \cdot s'_v(u'_q, v'_q).$$

Main difference between the discussed CDFs is that 2D-CDF represents a monotone increasing function in both axes whereas modified CDF does not have this property.

In addition to extracted maxima, secondary maxima may be determined by fitting straight lines (regression lines) to the set of ridge points, which have to run through one of the main maxima. The set of ridge points is limited by using only those points which lie inside a 10° pie segment. By calculating a weighted sum of point positions, secondary maxima are detected. Fig. 1 shows the u'v' histogram of map scene of Fig. 3. Maxima are represented by squares, secondary maxima by circles, and ridge points by triangles.

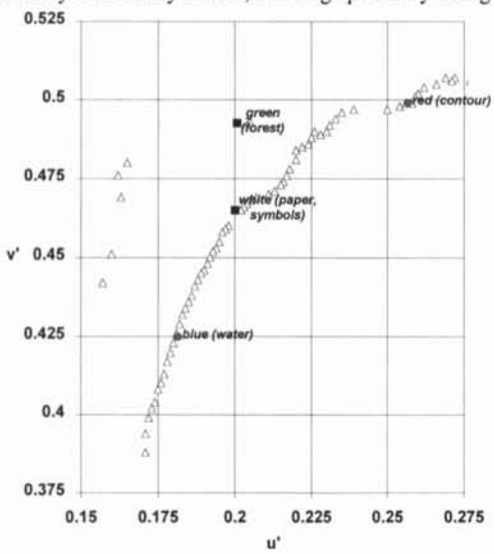

Fig. 1: Maxima and ridges in u'v' histogram.

Segmentation based on additive color mixture laws: Segmentation is primarily based on a distance measure from additive color mixture lines instead of distance from cluster centers. By applying this technique, misclassifications of additively mixed colors (mixels) may be avoided.

In a first step, colors located near to a cluster center (i.e. u'v' histogram maxima or secondary maxima) are classified (cf. Fig. 2). For all other pixels P_n, which chromaticity is not lying inside the rejection radius, the distance from all color mixture lines (i.e. straight lines connecting two cluster centers) is computed. Pixels is classified to be a mixture of those color pair, which mixture line is nearest to the chromaticity of pixel P_n. Additionally, chromaticity distance from the pixel's chromaticity coordinates to the cluster centers must be less than the distance between cluster centers itself. Subsequently, pixel P_n is classified to belong to one of the clusters by applying a minimum distance criteria.

Final step segmentation of the pixels grouped in the cluster paper/black using a luminance criteria. This may be done by applying the 1D-segmentation technique described in [Seza1990].

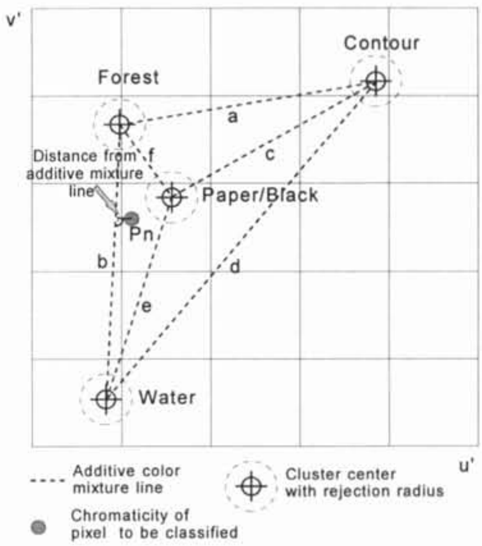

Fig. 2: Segmentation using additive color mixture laws.

RESULTS

Segmentation results of a scanned map scene (cf. Fig. 3) are compared to those of a standard minimum distance classifier. The original print contains the colors blue (water), green (forest), red (contour), black (symbols) and white (paper) and was scanned at a resolution of 1020dpi and 24 bit RGB. Fig. 4a and 4b show the results of segmentation of color layer red (contours) using the proposed technique versus minimum distance method. Fig. 5a and 5b shows the results for the color layer blue (water). Especially region border are much clearer using the new method.

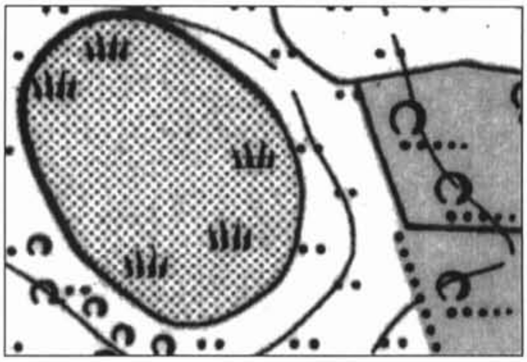

Fig. 3: Original map scene.

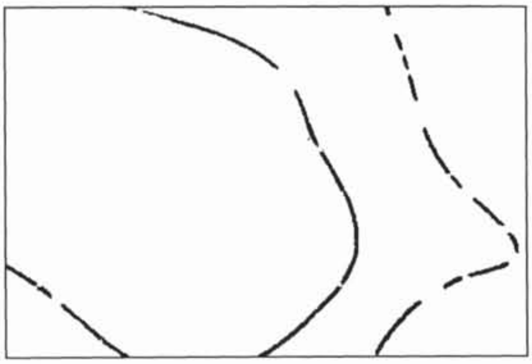

Fig. 4a: Layer "red" produced by new method.

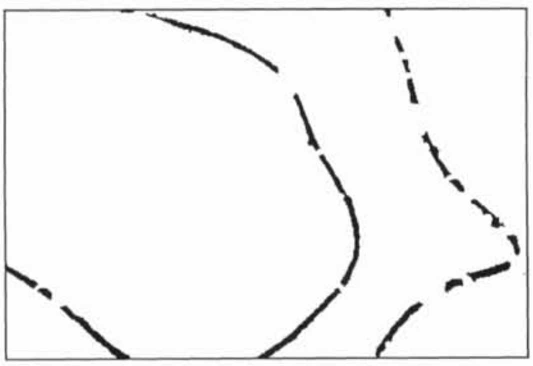

Fig. 4b: Layer "red" produced by min. distance method.

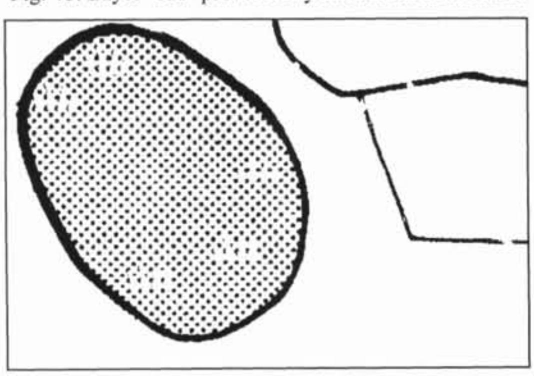

Fig. 5a: Layer "blue" produced by new method.

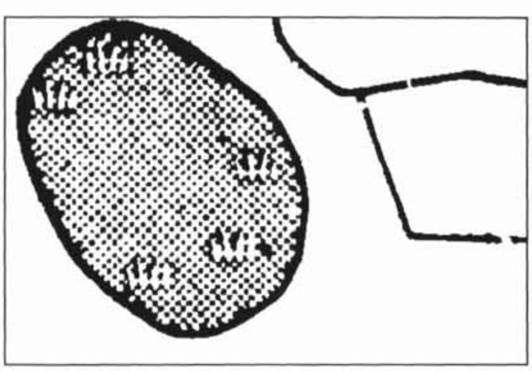

Fig. 5b: Layer "blue" produced by min. distance method.

CONCLUSION

The proposed segmentation technique was implemented as part of an automatic map analysis system (PROMAP [Laut1992] [Ebi1994]). Results of subsequent map recognition steps like object recognition or vectorization could be improved considerably. Especially vectorization results are much more clearer on a layer produced using the new technique instead of conventional methods. Thus, symbolic analysis by PROMAP using knowledge-based techniques could be improved.

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