Fuzzy Watershed for Image Segmentation

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Abstract

- The representation of the RGB color space points in spherical coordinates allows to retain the chromatic components of image pixel colors, pulling apart easily the intensity component.
- This representation allows the definition of a chromatic distance.
- Using this distance we define a fuzzy gradient with good properties of perceptual color constancy.
- In this paper we present a watershed based image segmentation method using using this fuzzy gradient.
- Oversegmentation is corrected applying a region merging strategy based on the chromatic distance defined on the spherical coordinate representation.

Spherical coordinates

- Chromaticity coordinates $\Psi_c = \{r, g, b\}$ correspond to the projection of c on the chromatic plane Π_Ψ, which is defined by the collection of vertices $\{(1,0,0),(0,1,0),(0,0,1)\}$ of the RGB cube which define the Maxwell's chromatic triangle along the chromatic line defined as $L_c = \{y = k \cdot \Psi_c; k \in \mathbb{R}\}$.
- In other words, all the points in line L_c have the same chromaticity Ψ_c.
- Chromaticity is a robust color characterization, which is is independent of illumination intensity and preserves the geometry of the objects in the scene.

Spherical coordinates

- $\mathbf{I} = \left\{\mathbf{I}(x); x \in \mathbb{N}^2\right\} = \left\{(R,G,B)_x; x \in \mathbb{N}^2\right\}$, where x refers to the pixel coordinates in the image grid domain, we denote the corresponding spherical representation as $\mathbf{P} = \left\{\mathbf{P}(x); x \in \mathbb{N}^2\right\} = \left\{(\phi,\theta,l)_x; x \in \mathbb{N}^2\right\}$, so we will use $(\phi,\theta)_x$ as the chromaticity representation of the pixel's color. Sometimes we use the notation $x = (i,j)$.

The chromatic distance in the RGB space

$P(x) = P_x = (\phi, \theta)_x; x \in \mathbb{N}^2$. For a pair of image pixels x and y, the color distance between them is defined as:

$$\angle(P_x, P_y) = \sqrt{(\theta_y - \theta_x)^2 + (\phi_y - \phi_x)^2}, \quad (1)$$

Chromatic gradient operator

We formulate a pair of Prewitt-like gradient pseudo-convolution operations on the basis of the above distance.

- The row pseudo-convolution is defined as

$$CG_R(P(i,j)) = \sum_{r=-1}^{1} \angle(P(i-r,j+1), P(i-r,j-1)),$$

and the column pseudo-convolution is defined as

$$CG_C(P(i,j)) = \sum_{c=-1}^{1} \angle(P(i+1,j-c), P(i-1,j-c)),$$

so that the color distance between pixels substitutes the intensity subtraction of the Prewitt linear operator. The color gradient image is computed as:

$$CG(x) = CG_R(x) + CG_C(x) \quad (2)$$

A Fuzzy Color Gradient

- Inspired in the human vision, diferent retinal cells need diferent energy for its activation.
- Cones are vey sensitive to intensity wheras rods need more energy for its activation, whose can detect the cromaticity. Depending of the sourface radiance, these retinal cells can be activated.
- We follow similar approach in order to define our fuzzy chromatic distance.
- For pixels with high intensity we are going to use the chromatic gradient defined in equation 2, whereas for pixels with poor illumination are going to use the conventional linear intensity gradient.

A Fuzzy Color Gradient

- We use a fuzzy membership function $\alpha(x)$ who gives the membership degree to the "well illuminated pixels class", on the other hand, its standard complement function $\overline{\alpha}(x) = 1 - \alpha(x)$ gives the membership degree to the "poor illuminated pixels class". It is defined as follows

$$\alpha(x) = \begin{cases} 0 & I(x) < a \\ \exp\left(\frac{-(c - \frac{I(x)-a}{b-a})^2}{2\sigma^2}\right) & a \leq I(x) < b \\ 1 & b \leq I(x) \end{cases}, \quad (3)$$

where $I(x)$ is the pixel intensity. For intensity values below a threshold a it is an intensity gradient, for values above another threshold b it is a chromatic gradient, and for values between both it is a mixture of the two kinds of gradients whose mixing coefficient is gaussian function of the image intensity.

A Fuzzy Color Gradient

- This idea is expressed mathematically as a convex combination of the two gradient operators:

$$FG(x) = \alpha(x)\, CG(x) + \overline{\alpha}(x)\, G(x) \tag{4}$$

Fuzzy Watershed Image Segmentation

- Watershed transformation is a powerful mathematical morphology technique for image segmentation.
- The watershed transform considers a bi-dimensional image as a topographic relief map.
- The value of a pixel is interpreted as its elevation.

Fuzzy Watershed Image Segmentation

- The watershed lines divide the image into catchment basins, so that each basin is associated with one local minimum in the topographic relief map.
- The watershed transformation works on the spatial gradient magnitude function of the image.
- The crest lines in the gradient magnitude image correspond to the edges of image objects.

General Schema

- The general schema of the watershed method consists of a flooding process which performs a region growing based on the ordered examination of the level sets of the gradient image.
- In fact, an ordered succession of thresholds are applied to produce the progression of the flooding.
- The image is examined iteratively *n* times, each iteration step the threshold is raised and pixels of the gradient image falling below the new threshold are examined to be labeled with a corresponding region.
- Initially each region will contain the source of its catchment basin when the flooding level reaches it.

General Schema

- Each flooded region is also characterized by a chromaticity value, that corresponds to the source pixel chromaticity.
- This chromaticity value is used to perform region merging simultaneously with the flooding process.
- A pixel whose neighboring pixels belong to different regions is a watershed pixel. When a watershed pixel is detected, the adjacent regions may be merged into one if the chromatic distance between the region chromatic values is below a chromatic threshold.

General Schema

- The merged region chromatic value is the average of that of the merged regions.
- The final labeling of the image regions is performed taking into account the equivalences established by the merging process.
- Watershed pixels whose adjacent regions do not merge into one are labeled as region boundary pixels and retain their chromaticity.

Experimental results

The general watershed-merge method is parametrized by:

- The number of iterations n, which determines the resolution of the flooding process going over the gradient magnitude image level sets.
- The gradient operator used to compute the gradient magnitude image, which can be either the intensity gradient $G(x)$ of equation or the fuzzy gradient $FG(x)$ of equation 4.

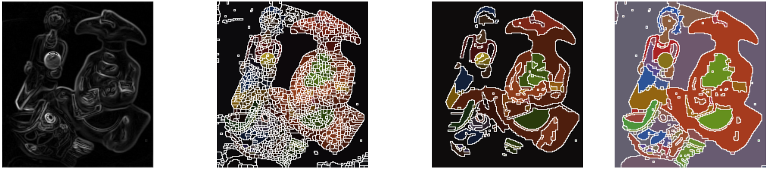
Experimental results

- The color representation of the image. Assuming the RGB space, it can be either the Cartesian representation $\mathbf{I}(x)$ or the zenithal and azimuthal angles of the spherical representation $\mathbf{P}(x)$. This selection determines the selection of the chromatic distance.
- The chromatic distance, which can be either the Euclidean distance in the RGB Cartesian space, or the chromatic distance of equation 1.
- The chromatic distance threshold δ, which determines the chromatic resolution of the region merging process.

Experimental results (intensity)

Original image

Gradient | Watershed | Segmentation



(a) (b) (c) (d)

Figure: Image segmentation results with different parametrizations

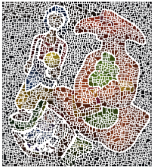
Experimental results (chromaticity)

Original image

Gradient

(e)

Watershed



(f)

Segmentation

(g)

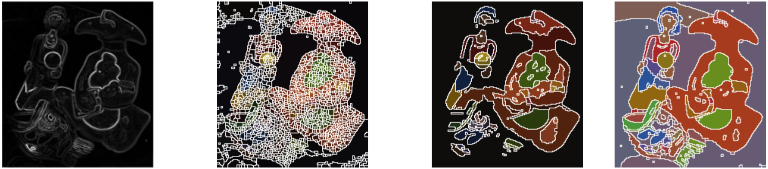
(h)

Figure: Image segmentation results with different parametrizations

Experimental results (fuzzy)

Original image

Gradient | Watershed | Segmentation



(i) (j) (k) (l)

Figure: Image segmentation results with different parametrizations

Conclusions

- This work introduces a fuzzy watershed and region merging segmentation based on the zenithal and azimuthal angles of the spherical representation of colors in the RGB space.
- These definitions allows the construction of a robust fuzzy chromatic gradient that we use to realize a robust chromatic watershed segmentation.
- This gradient operator has good color edge detection in lightened areas and does not suffer from the noise in the dark areas.
- The fuzzy watershed is complemented by a region merging based on the defined chromatic distance.

Conclusions

- We give a general schema of the algorithm performing both watershed and region merging.
- Out proposal can be stated by this algorithm fixing the color representation, gradient operator, and region merging distance.
- We compare our approach with other algorithms obtained with different setting of the general schema, obtaining the best qualitative segmentation.

Thanks for your attention.
Time for questions.