A Hybrid Color Distance for Image Segmentation

R. Moreno, M. Graña, A. d'Anjou

Computational Intelligence Group, Universidad del País Vasco
http://www.ehu.es/ccwintco

February 4, 2011

Introduction

- We'll propose a hybrid color distance is inspired in the human vision system.
- It simulates the sensitivity to intensity and chromaticity of the the retina's cells: cones and rods.
- This approach provides excellent edge detection and is the core of our method.
- The segmentation method depends on thi hybrid distance.

Spherical Coordinates and Chromaticity

- We are interested in the correspondence between the angular parameters (θ, ϕ) an the chromaticity Ψ.
- An image pixel's color corresponds to a point in the RGB color space $\mathbf{c} = \{R_{\mathbf{c}}, G_{\mathbf{c}}, B_{\mathbf{c}}\}$.
- The vector going from the origin up to this point can be represented using spherical coordinates $\mathbf{c} = \{\theta_{\mathbf{c}}, \phi_{\mathbf{c}}, l_{\mathbf{c}}\}$
  - Where θ is zenithal angle, ϕ is the azimuthal angle and l is the vector's magnitude.

Spherical Coordinates and Chromaticity

- In the RGB color space, chromaticity $\Psi_\mathbf{c}$ of a color point is represented by its normalized coordinates $r_\mathbf{c} = \frac{R_c}{R_\mathrm{c}+G_\mathrm{c}+B_\mathrm{c}}$, $g_\mathbf{c} = \frac{G_c}{R_\mathrm{c}+G_\mathrm{c}+B_\mathrm{c}}$, $b_\mathbf{c} = \frac{B_\mathrm{c}}{R_\mathrm{c}+G_\mathrm{c}+B_\mathrm{c}}$, such that $r_\mathbf{c} + g_\mathbf{c} + b_\mathbf{c} = 1$.
- That is, chromaticity corresponds to the projection on the chromatic plane Π_Ψ, defined by the collection of vertices of the RGB cube $\{(1,0,0),(0,1,0),(0,0,1)\}$, along the line defined as $L_\mathbf{c} = \{y = k \cdot \Psi_\mathbf{c}; k \in \mathbb{R}\}$.

Spherical Coordinates and Chromaticity

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

DRM expressed in Spherical Coordinates

- The Dichromatic Reflection Model explains the perceived color intensity $\mathbf{I} \in \mathbb{R}^3$ of each pixel in the image as addition of two components
  - One diffuse component $\mathbf{D} \in \mathbb{R}^3$ and a specular component $\mathbf{S} \in \mathbb{R}^3$.
- The diffuse component refers to the chromatic properties of the observed surface, while the specular component refers to the illumination color.

DRM expressed in Spherical Coordinates

- A scene with several surface colors, the DRM equation must assume that the diffuse component may vary spatially, while the specular component is constant across the image domain.
- In spherical coordinates is expressed below:

$$\mathbf{I}(\mathbf{x}) = (\theta_{\mathbf{D}}(\mathbf{x}), \phi_{\mathbf{D}}(\mathbf{x}), I_{\mathbf{D}}(\mathbf{x})) + (\theta_{\mathbf{S}}, \phi_{\mathbf{S}}, I_{\mathbf{S}}(\mathbf{x}))$$

For diffuse pixels (it means, pixels without specular component) the zenithal ϕ and azimuthal θ angles are almost constant, while they are changing for specular pixels (it means, pixels with specular component), and dramatically changing among diffuse pixels belonging to different color regions.

Edge and Distance

- An edge appears in the image when two neighboring pixels have different properties.
- Edge measurement is obtained computing this distance among neighboring pixels.

Edge and Distance

- Intensity is necessary for achromatic differences detection
- Chromaticity is the best for color diferences detection
- Due to the uniform noise distribution, chromaticity is very sensitive in dark regions
- In dark regions intensity is more stable that chromaticity
- Chromatic stability grows when the illumination is better.

Hybrid Distance

- This transition is expressed with the graph showed in the Fig. 1.

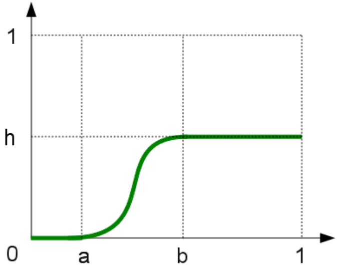

Figure: Chromatic activation function α

Hybrid Distance

- For values below a it is inactive.
- For values between a and b it goes from its minimum energy to its maximum energy h following a sinusoidal shape.
- Finally for values bigger that b its energy is always h.
- The three parameters a, b, h are in the range $[0, 1]$.
- The region under the green line is the chromatic importance
- The region over this line is the intensity importance.

Hybrid Distance

The function $\alpha(I)$ depends of the image intensity I.Its mathematical expression is as follows:

$$\alpha(I) = \begin{cases} 0 & I \leq a \\ \frac{h}{2} + \cos\left(\frac{(I-a)\cdot\pi}{b-a} + \pi\right) & a < I < b \\ h & I \geq b \end{cases} \qquad (1)$$

where i depends on the intensity.
To apply this distance to two colors we compute $I = |I_{\mathbf{c_1}} - I_{\mathbf{c_2}}|/2$ where $I_{\mathbf{c}_1}, I_{\mathbf{c}_2}$ are the intensity component I of the spherical coordinates of the colors $\mathbf{c}_1, \mathbf{c}_2$ and we can express it as $\alpha(\mathbf{c}_1, \mathbf{c}_2)$

Hybrid Distance

Now we can formulate an hybrid distance between any two colors $\mathbf{c}_1, \mathbf{c}_2$ as follows:

$$d_H(\mathbf{c}_1, \mathbf{c}_2) = (1 - \alpha(\mathbf{c}_1, \mathbf{c}_2)) \cdot d_I(\mathbf{c}_1, \mathbf{c}_2) + \alpha(\mathbf{c}_1, \mathbf{c}_2) \cdot d_C(\mathbf{c}_1, \mathbf{c}_2) \quad (2)$$

where

- d_I is an intensity distance as $d_I(\mathbf{c}_1, \mathbf{c}_2) = |I_{\mathbf{c}_1} - I_{\mathbf{c}_2}|$
- d_C is a chromatic distance as $d_C(\mathbf{c}_1, \mathbf{c}_2) = \sqrt{(\theta_{\mathbf{c}_1} - \theta_{\mathbf{c}_2})^2 + (\phi_{\mathbf{c}_1} - \phi_{\mathbf{c}_2})^2}$.

Segmentation

- Segmentation is a partition of the image domain set F into connected subsets or regions $(S_1, S_2, ..., S_n)$ such that $\bigcup_{i=1}^{n} S_i = F$ with $\forall i \neq j, S_i \cap S_j = \varnothing$.
- This segmentation method is based is the proposed hybrid distance.
- The algorithm examines all the pixels in sequence, assigning them labels according to the labeling of the pixels in its neighborhood.
- We consider 8-connectivity, so all the operations refer to the pixels' 8-neighborhood $N_8(p)$.

Segmentation

- Four parameters configure the algorithm behavior.
  - On one hand the distance parameters a, b, h previously explained.
  - On the other hand a threshold δ to test color similarity.
    - We decide that two colors $\mathbf{c}_1, \mathbf{c}_2$ are equivalent for segmentation purposes if $d_H(\mathbf{c}_1, \mathbf{c}_2) < \delta$.
- We will call nearest neighbors to the subset of $NN(p) \subseteq N_8(p)$ pixels with equivalent colors.

Segmentation

- Pixels in $NN(p)$ may be labeled or not, and, if some of them are labeled, the same or different labels may occur.
- If all $NN(p)$ pixels have the same label,
  - the current pixel p and all unlabeled pixels in $NN(p)$ will assume this label.
- When pixels in $NN(p)$ have different labels,
  - it means that current pixel is at a boundary point between some previously labeled regions whose colors are equivalent, and therefore we must merge them in an unique label, this is known as "region merging".
  - Again, all the pixels in $NN(p)$ are labeled according to the result of the region merging.

Segmentation

- Contrary to other labeling algorithms, a special feature of this algorithm is that when examining a pixel we can assign labels to more than one pixel.
- The current pixel is always labeled in the current iteration, however we make profit from current neighborhood information to label pixels that are ahead in the examination procedure.
- This anticipatory strategy speeds up the process.

Experimental Results

- The natural output of a segmentation method is a labels' vector, in this case is a bi-dimensional integer matrix, where each number is linked to a label.
- For a good visual supervision, the output images are drawn using the label's chromaticity and an uniform intensity ($I = 0.7$).

Experimental Results

- To validate the proposed segmentation method we will experiment with two different kind of images, on one hand the well-know Berkeley image database.
- And on the other hand a private collection of images taken by the robot NAO .
- The parameter settings for the experiments are: $\delta = 0.02$, $a = 0.2$, $b = 0.4$ and $h = 0.5$

Experimental Results

- Respect to the first experiment, using the Berkeley database, images are very different each others and we are using the same parameters and as we can see results are goods.

Experimental Results

Figure: Experimental results using Berkeley database

Experimental Results

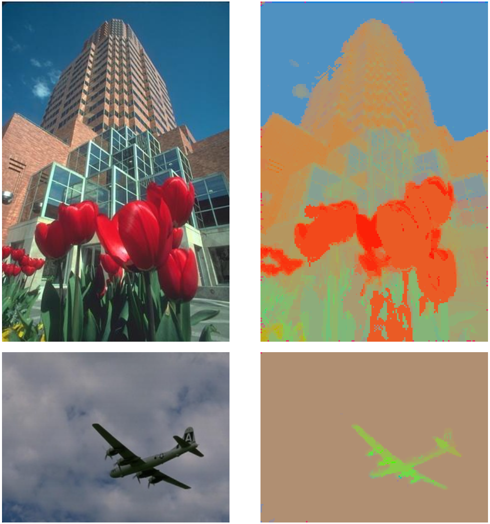

Figure: Experimental results using Berkeley database

Experimental Results

Figure: Experimental results using Berkeley database

Experimental Results

Respect to the second experiment, images are taken in similar illumination conditions, therefore results are more stable than in the first experiment. It is important to realize the good results avoiding shines and detecting correctly regions with different chromatic properties.

Experimental Results

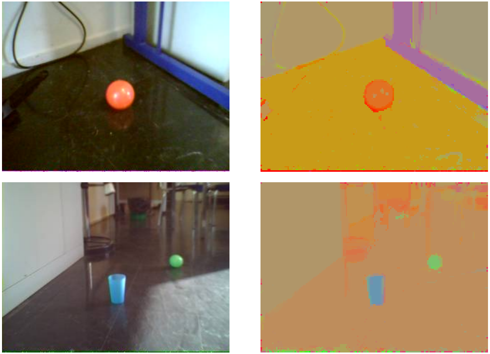

Figure: Robot Images

Experimental Results

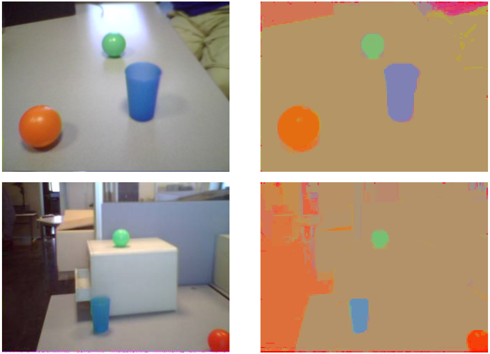

Figure: Robot Images

Conclusions

- In this work we propose a segmentation method starting with a physical approach of the reflectance phenomenon, and hence grounding our method in the dichromatic reflexion model.
- The spherical coordinate interpretation of the RGB color space is the best way to take profit from the DRM theory in the RGB color space.
- In spherical coordinate representation it is very easy to detect diffuse regions in the image.

Conclusions

- To design a segmentation algorithm we apply this distance in a neighborhood-based labeling algorithm.
- The introduced method follows a human vision inspiration and it is very versatile thanks to its parametrization and it can be adapted to different expectations of segmentation.
- As we can see in the experimental results it has a good behavior in shines and shadows.
- As further works we will to study an automatic estimation of the parameters a, b, h of this method.

Thanks

Thanks for your attention!