Colour-based Segmentation of Carry-on Baggage Images

Slobodan Ribarić, Kristina Kiš
Faculty of Electrical Engineering and Computing
University of Zagreb
Unska 3, 10000 Zagreb, Croatia
E-mail: slobodan.ribaric@fer.hr
kristina.kis@fer.hr

Abstract

Electronic detection devices such as X-ray machines and CAT scanning devices allow screening of carry-on baggage in order to detect threat objects (handguns, knives, ammunition, etc.). Obtained images are colour-coded to assist material discrimination. Image processing techniques are used to support pre-board screeners in a decision-making process. A segmentation method for extracting regions of interest from baggage images is described in this paper. The method consists of partitioning the image into homogenous regions using the split and merge algorithm. The following homogeneity predicates are used: the intensity (for regions which are surely achromatic), the hue (for surely chromatic regions) and the combination of hue and intensity (for regions which are neither surely chromatic nor achromatic). The experimental results of the segmentation of baggage images are given.

1. Introduction

The detection of threat objects (such as handguns, knives, grenades, etc.) in imagery obtained from X-ray or CAT based screening stations is an important problem for airport security. Most detection systems now in use are almost totally reliant on the training, skill and interest of a human operator [1]. The automatic detection of threats in imagery of passenger carry-on baggage will lead to enhanced and consistent security screening in national and international airports, as well as in government institutions, courts, museums, galleries, etc. Systems for automatic detection of threats are usually founded on *machine intelligence based image analysis* [2], [3]. Such systems combine the following processing-step sequence: image capture and enhancement, segmentation, feature extraction, matching of features to models and application of domain knowledge to recognize objects in the scene and their attributes [4]. The region-based segmentation can be viewed as one of the first operations that a computer vision system is to perform in order to separate regions of interest from the background [12]. These regions are processed by the remaining stages of the vision system. There are many segmentation techniques that are based on colour [5], [6], [7], [8].

This paper presents segmentation method of colour baggage images based on the two perceptual attributes: the hue H and the intensity I. The proposed region segmentation method is based on the split and merge algorithm [9], [10] using the following homogeneity predicates: the intensity (for regions that are surely achromatic), the hue (for surely chromatic regions) and the combination of hue and intensity (for regions that are neither surely chromatic nor achromatic). The paper is organized as follows: After this Introduction, Section 2 deals with image representation, a HSI model and chromaticity degree of baggage images. Section 3 describes the homogeneity predicates and the split and merge algorithm. The experimental results of the proposed method for baggage images are given in Section 4.

2. Image representation by HSI model

Obtained baggage images are 24-bit (RGB) colour bitmaps of size 768 × 576 pixels. The images are converted from the RGB to the HSI colour model [8], [11]. The HSI colour model is closely related to the way in which human beings perceive colour. It decouples the intensity component I from the colour information represented by hue and saturation components. The hue H is a colour attribute that describes a pure colour, while saturation S represents a degree to which a pure colour is saturated with white light [11]. A model for representing a colour in a 3-D colour space used further in this section is based on a Cartesian coordinate system with axes corresponding to H, S and I components. If all colour components are normalised (reduced to range [0, 1]), then the colour subspace of interest is represented with the unit cube. The model characteristics do not change if we expand all the colour components to the range [0, 255].

Any plane perpendicular to H axis (with a constant H value) is called a saturation-intensity plane.

Prior to performing the split and merge algorithm, each pixel P of the image has to be described by three relevant details: its pure colour, intensity and chromaticity degree [8]. Converting a pixel's colour information to HSI colour space gives us information about its pure colour (the hue) and the intensity. As perceived by humans, the most discriminant attribute when extracting objects from a scene is the object's hue. However, in achromatic areas of an image (with low saturation or low intensity) the hue is meaningless, and the intensity becomes the discriminant attribute. In the process of extracting objects from an image it is necessary to estimate chromaticity characteristics of every pixel in the image. After that pixels can be classified according to the appropriate attribute(s). Chromaticity of a pixel P can be described with its chromaticity degree $c(P)$ as follows [8]:

$c(P) = 1$ ↔ pixel P is surely chromatic
$c(P) = 0$ ↔ pixel P is surely achromatic
$c(P) > 0.5$ ↔ pixel P is rather chromatic
$c(P) < 0.5$ ↔ pixel P is rather achromatic

We can see that $c(P)$ does not declare a pixel as a chromatic or achromatic, but rather introduces a level to which a pixel can be considered chromatic. It divides the colour space to the chromatic subspace (chromatic zone) with pixels classified as chromatic ($c(P) > 0.5$), and the achromatic subspace (achromatic zone) where pixels are considered to be achromatic ($c(P) < 0.5$). We can also define the transition zone as a subspace where $c(P)$ is neither 0 nor 1 ($0 < c(P) < 1$). Chromaticity degree is a function of pixel's saturation and intensity, and does not depend on its hue [8].

A method of identifying $c(P)$ used in this experiment consists of estimating a constant splitting line l (see Fig. 1) in a saturation - intensity plane of a HSI colour cube, and estimating a constant half-width of the transition zone Δ. The splitting line l is used to estimate the border between chromatic and achromatic colour space zones and correlates saturation and intensity components. It is approximated with part of a circle whose centre lies outside the square where S and I values are defined. The half-width of the transition zone Δ represents an estimation of maximal (Euclidian) distance between a pixel P and the splitting line l, where P is neither surely chromatic nor surely achromatic.

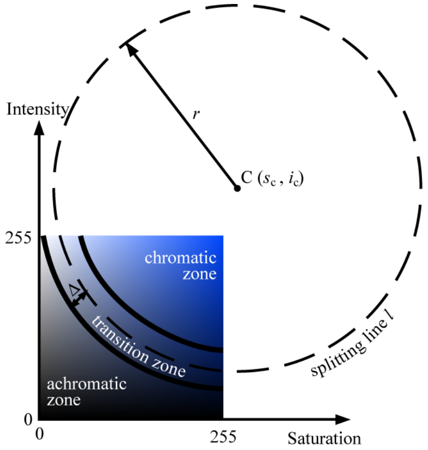


Figure 1. Splitting line and transition zone

The chromaticity degree of a pixel P can be calculated as follows [8]:

$$c(P) = \frac{1}{2}(1 + s(P)\tanh(2\frac{d}{\Delta})) \qquad (1)$$

where d is the distance between a pixel P and the splitting line l, and $s(P)$ defines a half-space the pixel belongs to:

$s(P) = 0$ if P is on the splitting line l
$s(P) = -1$ if P belongs to the half-space that contains the origin (achromatic half-space)
$s(P) = +1$ if P belongs to the half-space that does not contain the origin (chromatic half-space)

We can see that equation (1) produces $c(P)$ similar to the original definition:

$c(P) > 0.98$ ↔ pixel is surely chromatic for $d > \Delta$ and $s(P) = +1$
$c(P) < 0.02$ ↔ pixel is surely achromatic for $d > \Delta$ and $s(P) = -1$
$0.5 < c(P) \leq 0.98$ ↔ pixel is rather chromatic for $d \leq \Delta$ and $s(P) = +1$
$0.02 \leq c(P) < 0.5$ ↔ pixel is rather achromatic for $d \leq \Delta$ and $s(P) = -1$

Using a circle with a centre point outside the S-I square as a splitting line simplifies calculating distance d between arbitrary pixel P and the line:

$$d = \left| d(P, C) - r \right| \qquad (2)$$

where $d(P, C)$ is the distance between pixel P and centre C of the circle, and r is radius of the circle. Under the given conditions, $s(P)$ can be calculated with:

$$s(P) = -\mathrm{sgn}(d(P, C) - r) = \mathrm{sgn}(r - d(P, C)) = \mathrm{sgn}(\tanh(r - d(P, C))) \qquad (3)$$

Let the splitting circle l have the centre point C with coordinates (s_c, i_c). The chromaticity degree of a pixel P with coordinates (s_p, i_p) can now be calculated with:

$$c(P) = \frac{1}{2}(1 + \tanh(2\frac{r - \sqrt{(s_p - s_c)^2 + (i_p - i_c)^2}}{\Delta})). \qquad (4)$$

In this experiment estimated constants are: $s_c = 255$, $i_c = 290$, $r = 210$ and $\Delta = 50$ (as shown in Figure 2).

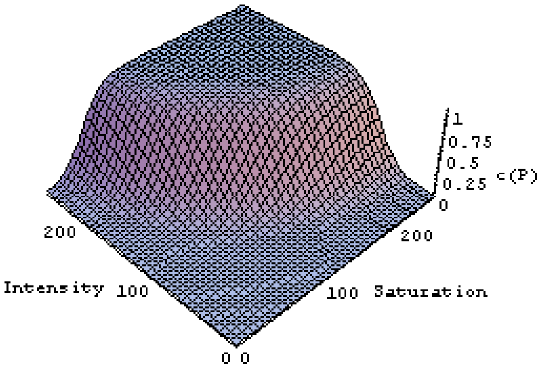


Figure 2. Chromaticity degree

3. The split and merge algorithm

Formally, region segmentation can be defined as a method to partition an image S into subimages, called regions R_1, R_2, R_3, ... R_k, such that [10]:

i) $\bigcup_{i=1}^{k} R_i = S$, $(\{S_i\}$ is an exhaustive partitioning),

ii) $R_i \bigcap R_j = \varnothing$, $i \neq j$, $(\{S_i\}$ is an exclusive partitioning),

iii) $F(R_i) = true$ for all i, where F is a homogeneity predicate, i.e. each region R_i satisfies the predicate,

iv) Pixels belonging to adjacent regions, when taken jointly, do not satisfy the predicate.

3.1. The split and merge algorithm description

The algorithm uses a quad tree representation for images. A quad tree is a tree whose nodes are either leaves or have four children. Each leaf in the quad tree is associated with a square area of the image and belongs to a particular region. Regions in the image and relationships among them are described in a region adjacency graph (RAG). The split and merge algorithm consists of forming initial regions in the image, and then performing the following steps for each region [9], [10]:

1. Pick a region R and check if it is homogenous. Region R is homogenous if its characteristics satisfy a certain homogeneity predicate $F(R)$:
   $F(R) = true \leftrightarrow R$ is homogenous.
   If $F(R) = false$, divide the region into four subregions.
2. For any two or more neighbouring regions R_1, R_2, .., R_n in the image check $F(R_1 \cup R_2 \cup ... \cup R_n)$. If $F(R_1 \cup R_2 \cup ... \cup R_n) = true$, merge the n regions into a single region.
3. Repeat the first two steps until no more splits or merges occur.

3.2. The homogeneity predicate.

Efficiency of a segmentation algorithm greatly depends on selection of the homogeneity predicate. When segmenting a grey scale image, a good predicate could be defined using standard deviation of grey values. Due to complex chromaticity properties of baggage images, it is not always obvious which standard deviation should be calculated. Let us consider several cases:

(a) When every pixel in the region R is surely achromatic, region is considered homogenous if its standard deviation of intensity σ_I is small:

$$F(R) \text{ is true if } \sigma_I < T_I \qquad (5)$$

where T_I is a predefined threshold.

(b) If every pixel in R is surely chromatic, region is homogenous when its standard deviation of hue σ_H is smaller than a given threshold T_H:

$$F(R) \text{ is true if } \sigma_H < T_H \qquad (6)$$

(c) The region has constant chromaticity properties $c(R)$ but is neither surely chromatic nor surely achromatic:

$$F(R) \text{ is true if } k_H \cdot c(R) \cdot \sigma_H + k_I \cdot (1-c(R)) \cdot \sigma_I < 1 \qquad (7)$$

k_H and k_I are constant values where $k_H = 1/T_H$ and $k_I = 1/T_I$. $c(R)$ is a common chromaticity degree of each pixel in the region. Both intensity and hue standard deviations are significant for resolving region homogeneity. More chromatic regions depend more on their standard deviation of hue and less on the intensity standard deviation. For more achromatic regions, the standard deviation of intensity is more significant in estimating homogeneity. With $c(P) = 0$, equation (7) transforms to (5). For surely chromatic regions, (7) is equal to (6).

(d) The region has zero hue and intensity standard deviations, but contains a variable chromaticity degree. This implies that all pixels in the region have a common intensity and hue, but differ in their saturations. The region can be considered homogenous if its standard deviation of chromaticity σ_C is smaller than a threshold T_C:

$$F(R) \text{ is true if } \sigma_C < T_C \tag{8}$$

(e) Every other case can be considered as a combination of (c) and (d). Region chromaticity degree can be defined as:

$$c(R) = \frac{\sum_{i=1}^{n} c(P_i)}{n}$$

where n is the number of pixels in the region R. Homogeneity predicate is then:

$$\begin{gathered} F(R) \text{ is true if} \\ k_H \cdot c(R) \cdot \sigma_H + k_I \cdot (1-c(R)) \cdot \sigma_I + k_C \cdot \sigma_C < 1 \end{gathered} \tag{9}$$

with k_C equal to $1/T_C$. When standard deviation of chromaticity σ_C is small, $c(R)$ can be considered as a common chromaticity degree and equation (9) is equal to (7). With a considerable chromaticity standard deviation, $c(R)$ does not have the meaning of a common chromaticity degree and has a value different from 0 or 1. However, if hue and intensity standard deviations are small, (9) is similar to (8). With k_C well selected, $F(R)$ is false. With any further increase of either hue or intensity standard deviation, the left side of expression (9) increases and the truth-value of the predicate does not change.

The experimental results for segmenting baggage images are: $k_H = 0.15$, $k_I = 0.15$ and $k_C = 40$. Hue and intensity ranges are assumed to be [0, 255], while chromaticity range is [0, 1].

3.3. Region weight

Different colours in baggage images correspond to different materials. Colours of interest correspond to metal objects, and those are certain shades of blue (regardless of intensity) and colours with low intensity (regardless of hue). The weight of a region R ($w(R)$) is an evaluation of probability of R corresponding to metal. It consists of two parts: a hue part $w_H(R)$ and an intensity part $w_I(R)$, which are calculated separately:

$$w(R) = c(R) \cdot w_H(R) + (1 - c(R)) \cdot w_I(R) \tag{10}$$

The more chromatic a region is, more significant is its colour in estimating the region weight. Weight factor of more achromatic regions is based more on region's intensity. Region weight has range [0, 1]. Regions of interest have higher weight values.

The hue part of the region weight is a measure of distance between the region's mean hue h_R and an estimated pure metal colour h_M. It follows the Gaussian curve:

$$w_H(R) = \exp(-\frac{(h_R - h_M)^2}{2\delta_H^2}) \tag{11}$$

The most significant colour h_M is assumed to be in the middle of hue range (value 127). Constant δ_H determines slope of the curve (in this experiment $\delta_H = 20$). If h_R is close to h_M, the hue weight is close to 1.

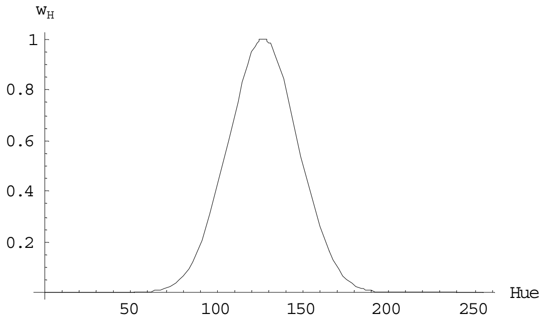


Figure 3. Hue region weight

The intensity weight has highest values for low region mean intensities i_R:

$$w_I(R) = 1 - \frac{1}{2}(1 + \tanh(2\frac{i_R - i_C}{255 - i_C})) \tag{12}$$

In this application constant intensity i_C where $w_I(R) = 0.5$ is equal to 150.

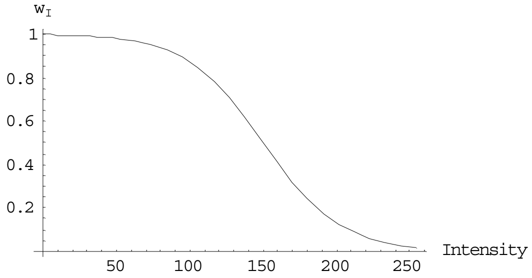
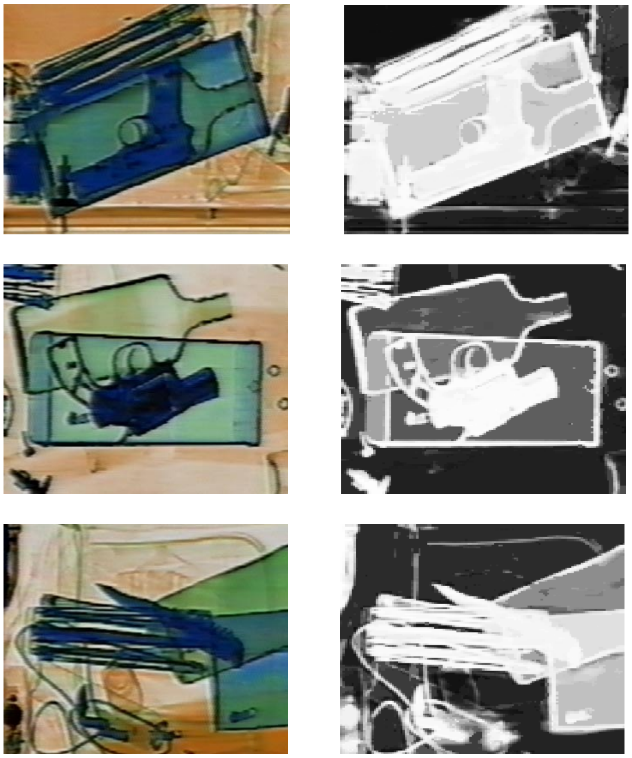
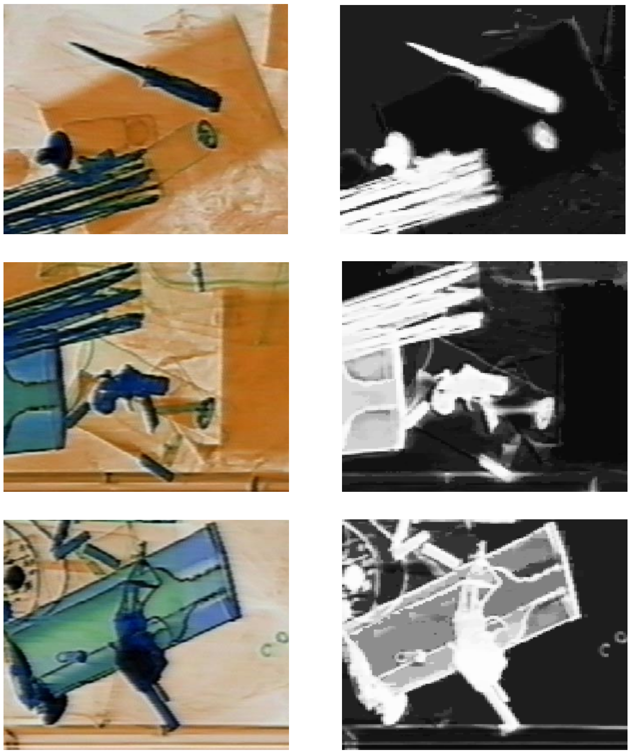


Figure 4. Intensity region weight

4. Experimental results

Described algorithm is demonstrated with the results presented on Figure 5. After segmenting the images, regions are coloured according to their weight so that the more important regions appear brighter. Both blue and black regions of the original images are recognized as regions of interest and contain high region weights. The algorithm was tested on 28 colour images with resolution 768 × 576 pixels. The mean computation time was 975 ms on a Pentium II 350 MHz computer with 128 MB of RAM.





(a) (b)

Figure 5. Examples of baggage images (a) and segmented images with indicated regions of interest

5. Conclusion

The first step of detecting threat objects in carry-on baggage images is extracting different objects from an image by segmenting the image into homogenous regions. The homogeneity criterion for extracting regions from a coloured image depends significantly on chromaticity properties of the image. The best segmentation results are achieved by introducing a measure of chromaticity for each region in the image called the chromaticity degree. Chromatic regions are then classified by their colour, while achromatic regions are formed according to their intensity properties. Since the chromaticity degree represents a level of region's chromatic characteristics, regions that are neither surely chromatic nor achromatic can use the right amount of both their colour and intensity properties in estimating homogeneity.

The segmentation is implemented using the well-known split and merge algorithm. The obtained regions from a baggage image are weighted according to their hue and intensity properties, which estimates the probability that a certain region corresponds to a metal object.

Acknowledgment

This work has been carried out within Project 00-7 *Development of a System for Automatic Detection of Threats in X-ray Imagery of Passenger Carry-on Baggage* funded by the Ministry for Science and Technology of the Republic of Croatia.

The experimental baggage images were taken at Zagreb Airport, Pleso. The threat objects are intentionally put into baggage only for research reasons in order to simulate real situations.

References

[1] R. S. Murphy, "Teaching Baggage Security Systems New Tricks", URL: http://www. gsetoday.com/back-is/May 98/InnerScan.html

[2] "Airline Baggage Security", URL: http://www.biocomputer.com/inner.html

[3] M. Sluser, R. Paranjape, "Probabilistic Relaxation Segmentation of Handguns in X-ray Imagery of Passenger Carry-on Baggage", *Proceedings of the IASTED Int. Conference Signal and Image Processing (SIP '98),* October 1998, Las Vegas, pp.603-607.

[4] R. Kasturi, R. C. Jain, *Computer Vision:* Advances *& Applications,* IEEE Computer Society Press, Los Alamitos, 1991.

[5] R. Ohlander, K. Price, D.R. Reddy, "Picture Segmentation Using a Recursive Splitting Method, *Comp. Graph. and Image Processing,* Vol. 8, 1978, pp. 313-333.

[6] Y. Ohta, *Knowledge-based Interpretation of* Outdoor *Natural Color Scenes,* Pitman Advanced Pub. Program, Boston, 1985.

[7] G. Healey, "Using Color for Geometry-insensitive Segmentation", *Journal of the Optical Society of America,* Vol. 6, No. 6, June 1989, pp. 929-937.

[8] P. Pujas, M-J. Aldon, "Robust Colour Image Segmentation", URL: http://www.lirmm.fr/~w3rob/Lochness/

[9] T. Pavlidis, *Structural Pattern Recognition,* Springer-Verlag, Berlin, 1977.

[10] R. Jain, R. Kasturi, B. G. Schunck, *Machine Vision,* McGraw-Hill, New York, 1995.

[11] R. C. Gonzalez, R. E. Woods, *Digital Image Processing,* Addison-Wesley Pub. Company, Reading, 1993.

[12] S. Ribarić, Ž. Perković, N. Pavešić, "Edge Detection By Using Focus Of Attention Area", *Proceedings of the 5th Int. Conference on Information Systems Analysis and Synthesis ISAS '99,* Vol. 6, Orlando, August 1999, pp.163-169.