Effect of color space on color image segmentation

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Abstract—A study of color image segmentation with its dependence on color space representation is presented. Segmentation has been one of the basic procedures in image processing. Because of the three-fold increase in color signal dimension as compared to black-and-white images, an advantage resulting from the choice of color space representation could be taken to enhance the performances of processes such as segmentation and feature matching. However, the choice of a particular color space is still largely application dependent. This work attempts to study a number of popular color space schemes on the basis of the maximum information that the space is able to convey to the segmentation process. Thus, a reduction in the complexity of the segmentation procedure is achievable when it is operating on a single color space domain. The amount of information contained in the segmented objects is adopted as a measure to determine the segmentation rule. Several aerial images over planted fields are employed in experiments and their satisfactory segmentation results are used to conclude the study.

I. INTRODUCTION

Image segmentation is the process of separating or classifying the pixels contained in an image into groups of coherent attributes. This process is regarded as one of the fundamental procedures in image processing together with, for example, contrast enhancement [1], feature extraction and association of correspondence. The image may be obtained in black-and-white or color and the latter may introduce an added degree of computational complexity and storage demand. However, color images contain much more information than that could be delivered by black-and-white images.

Segmentation can be performed using a number of methods such as histogram thresholding, feature clustering, use of fuzzy systems and neural networks [2]. Among these techniques, histogram thresholding is the technique that has been widely adopted while entropy-based thresholding is also very popular [3]. There is a number of designs that enable one to determine a proper threshold. For example, the minimization of the variance within a segmented object [4], the maximization of similarity using intelligent computation approaches [5] and the use of soft-computing techniques such as fuzzy logic [6]. Segmentation is inter-related to and can make use of results from image feature matching. In feature matching, intensity-based and edge-based comparison between candidate features [7] as well as rotation invariant template matching [8] are commonly employed.

The use of image segmentation can be found in a very large number of applications such as in surveillance. To name a few, man-made object can be identified from aerial images [9] which is attributed to an un-supervised segmentation process. In [10], buildings in an urban area are extracted from an aerial image. The result, in cooperation with data from the geographic information system, is applied in town planning and land-use monitoring. Moreover, in [11], moving objects such as road vehicles are detected from aerial surveillance video streams with the use of segmentation. This system has a high application potential in military, law-reinforcement and disaster response operations. The application of image segmentation in agriculture has also been reported. In [12], segmentation of objects, such as fruit, suffering from occlusion is addressed with a watershed-based approach. Planted crops on the ground can be identified [13] against noise and shadows using a mean-shift based technique.

Among the development of segmentation techniques and their applications in a variety of areas, it seems that a unified approach to the specific problem of color image segmentation on different color space representations has not been fully investigated. In this work, an attempt is made to study the effect of different color space representations on the performance of color image segmentation. The information content measured by entropy is used to select the color space domain such that it is the largest among other color spaces under test. The allocation of individual pixels into their corresponding segment is aimed at maximizing the total information and minimizing the difference between the information contained in the foreground/background objects. This principle is adopted in the design of a segmentation threshold. Aerial images of planted fields are used in experimental tests to verify the proposed approach.

The rest of the paper is arranged as follows. In Section II, several commonly used color spaces are reviewed. The determination of information content conveyed in a color space domain is described in Section III together with the design of the segmentation approached. Section IV presents the experiment results revealing the effect of color space on segmentation performance. Finally, a conclusion is drawn in Section V.

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II. COLOR SPACES

Images delivered by contemporary digital cameras capture the human perception of primary colors in a combination of tristimulus, namely, red (B), green (G) and blue (B) into electrical signals. Subsequent electronic processing of these color signals can take a number of different representation formats denoted as color spaces. Each format or space has its own advantages whether it is suitable for graphic display devices or transmission through radio television (TV) channels. In the context of processing, the choice of color space may have a paramount influence on the performance of procedures such as segmentation addressed in this work. The characteristics of several popular color spaces are briefly reviewed in the following. Interested readers are referred to the work in [2] for further information.

Here, it is assumed that a primary image is available from cameras in the RGB format and other spaces are obtained through appropriate transform operations. For instance, a color aerial image (over a planted field) of 200 × 150 pixel (width × height) and 256 levels in each RGB color, Fig. 1, is to be transformed into other color spaces.

![Fig. 1. An example color aerial image in RGB space, (a) color image, (b) R-component, (c) G-component, (d) B-component.](image)

A. YIQ

This space is used to encode color information in American TV systems. The \( Y \) signal represents the illumination intensity while \( I \) and \( Q \) (in-phase and quadrature phase) jointly describe the hue and saturation. The YIQ space is obtained from RGB through a linear transform. Here the RGB signals are each bounded within \([0, 1]\). The YIQ partially reduces the correlation of RGB components.

\[
\begin{bmatrix}
Y \\
I \\
Q
\end{bmatrix} = \begin{bmatrix}
0.299 & 0.587 & 0.114 \\
0.596 & -0.274 & -0.322 \\
0.211 & -0.253 & -0.312
\end{bmatrix} \begin{bmatrix}
R \\
G \\
B
\end{bmatrix}.
\]

B. YUV

The YUV color space is similar to the YIQ space except that it is used in European TV transmissions. The \( U \) and \( V \) components convey the color information. It is also able to reduce the inter-dependencies of the RGB components.

\[
\begin{bmatrix}
Y \\
U \\
V
\end{bmatrix} = \begin{bmatrix}
0.299 & 0.587 & 0.114 \\
-0.147 & -0.289 & 0.437 \\
0.615 & -0.515 & -0.100
\end{bmatrix} \begin{bmatrix}
R \\
G \\
B
\end{bmatrix}.
\]

C. \( I_1I_2I_3 \)

This color space is obtained from simple and efficient transformation as given below. The reduction in computation complexity may be useful in applications where real-time performance is critical.

\[
\begin{bmatrix}
I_1 \\
I_2 \\
I_3
\end{bmatrix} = \begin{bmatrix}
0.333 & 0.333 & 0.333 \\
0.500 & 0.000 & -0.500 \\
-0.250 & 0.500 & -0.250
\end{bmatrix} \begin{bmatrix}
R \\
G \\
B
\end{bmatrix}.
\]

D. HSI

The HSI color space is a commonly used color space in image processing. Color information is given by the hue (\( H \)). Saturation (\( S \)) reflects the color purity and the brightness is denoted by intensity (\( I \)). The hue signal is related to human color perception.

\[
\begin{bmatrix}
H \\
S \\
I
\end{bmatrix} = \begin{bmatrix}
\arctan(\sqrt{3}(G - B)/(2R - G - B)) \\
1 - \min(R, G, B)/I \\
(R + G + B)/3
\end{bmatrix}.
\]

E. HSV

The HSV color space is similar to the HSI space where the value (\( V \)) component is given by an alternative transformation as the maximum of the RGB components.

\[
\begin{bmatrix}
H \\
S \\
V
\end{bmatrix} = \begin{bmatrix}
\arctan(\sqrt{3}(G - B)/(2R - G - B)) \\
1 - 3 \times \min(R, G, B)/(R + G + B) \\
\max(R, G, B)
\end{bmatrix}.
\]

F. Effects on Segmentation Quality

The information contained in a color image is inherited from the scene and encoded in color space components. It is foreshadowed that different spaces may convey different amount of information, as shown in the next section, due to the construction of the transform process. Moreover, if the information content is limited, a subsequent segmentation process may be difficult due to the lack of discrimination capability.

III. ENTROPY-BASED SEGMENTATION

In this section, a segmentation procedure based on maximizing the information contents in the segmented foreground and background objects will be presented. The available information is determined by that is conveyed in the transformed color space.
A. Information Content

The information content measured from a color space component is obtained from the entropy calculated from the probability distribution. In addition to directly thresholding the distribution, information or entropy-based segmentation is able to provide a quality assessment on the segmented results [3]. This quantity is also used in this work.

Let the color image, for instance in RGB format, be given by

\[ \mathcal{I} = \{I_{ij}\}, \]

where \( I_{ij} = \{R_{ij}, G_{ij}, B_{ij}\} \) for \( i = 1, \ldots, v, j = 1, \ldots, u \), denotes the color magnitude of a pixel located in the image's \( ij \) location. Subscripts \( u, v \) are the width and height of the image. Note that the calculation of information content is independent of the color space.

For each color component, a histogram is constructed to give

\[ G_r = \{g_r^k\}, \]

where \( r \) is subscripts for the R component and \( k = 1, \ldots, \hat{k} \), \( (\hat{k} = 1000) \) is the bin index corresponding to the range of the component magnitude. Here, the number of bins is chosen for sufficient resolution and ease of computation. The histograms obtained from the example image given in Fig. 1 is illustrated in Fig. 2 together with the calculated entropy as described below.

![Histograms obtained from the example image](image)

For each histogram, the information content or entropy is calculated. The histogram is firstly normalized to give a probability distribution and the entropy is given by,

\[ H_r = - \sum g_r^k \log_2(g_r^k), \quad g_r^k = \frac{g_r^k}{\sum_{\forall k} g_r^k} \]

where \( g_r^k \) is the normalized histogram or the probability distribution of a given color space. It can be observed in Fig. 2, for a RGB color image, that different color spaces have different amount of information carried.

The color component that contains the maximum entropy among all other color components and in color spaces is selected as the distribution used for segmentation. That is

\[ c^* = \arg \max_c \{H_c\}, \]

where \( c \) is the index for each component within a color space and is also referred across all other color spaces. For example, with the six color spaces described in Section II, there are \( 3 \times 6 = 18 \) entropies available as candidate indicators for segmentation in this work.

B. Segmentation

The selected distribution with the maximum entropy is employed in the determination of a threshold to separate the image into foreground and background objects. For instance, let the distribution \( G_{c^*} = \{g_{c^*}^k\} \) be selected. A candidate threshold is obtained by an exhaustive search across the distribution such that the sum of the entropies of the foreground and background objects is maximized. It is also required that their difference is minimized. That is, a balance between total maximum information content and individual maximum information is sought as a segmentation design principle.

Let the candidate threshold be \( \tau \). Theforeground and background objects are determined as a function of the variables

\[ k_f = \{1, \ldots, \tau\}, \quad k_b = \{\tau + 1, \ldots, \hat{k}\}, \]

where \( k_f \) and \( k_b \) are the indices of foreground and background objects such that their pixel values in the selected color space fall within the range of the distribution that is to be segmented.

The threshold \( \tau \) is further adjusted across the distribution, such that \( 0 < \tau < \hat{k} \). Two entropies corresponding to the foreground and background objects are calculated by

\[ H_f^* = - \sum_{f \in k_f} g_{c^*}^f \log_2(g_{c^*}^f), \]

\[ H_b^* = - \sum_{b \in k_b} g_{c^*}^b \log_2(g_{c^*}^b). \]

The segmenting threshold \( \tau^* \) is selected in accordance to

\[ \tau^* = \arg \max_\tau \{H_f^* + H_b^* - |H_f^* - H_b^*|\}. \]

Thus, the segmented objects would carry a maximum total information due to \( H_f^* + H_b^* \) and a minimum information difference between objects contributed from \(-|H_f^* - H_b^*|\).

The foreground and background object are segmented as

\[ \mathcal{F} = \{I_{ij}^f\}, \quad \mathcal{B} = \{I_{ij}^b\}, \]

where \( I_{ij}^f \) are pixels such that their transformed space pixel within the foreground range of bins in the selected distribution of a color space. The background object \( \mathcal{B} \) is selected as all other pixels indexed by \( k_b^b \).
IV. Experimental Study

Two copies of aerial image over planted fields are used in the experiment to verify the proposed segmentation approach. Test image 1 covers a wider area while test image 2 is a zoomed-in version covering a smaller area.

A. Information Content

Information contents or entropies of the test images are calculated for the color spaces adopted in this study. Results are given in tables I and II. The subscripts, e.g. $H_1$, stand for the entropy contained in the $R$ space in a RGB image. Similarly, $H_1$ of the YIQ space indicates the entropy conveyed by the intensity component $Y$.

As expected, the entropies calculated are different across color spaces even for the same given image. In test image 1, the maximum entropy equal to 5.8489 is found in the $V$ space of the YUV representation. In test image 2, a maximum entropy of 5.9645 is observed in the $U$ space of the YUV representation. It is interesting to note that the intensity space for both images carry a moderate amount of information instead of being the maximum. Thus, segmentation of color images by conversion into gray-level images may not be very desirable.

<table>
<thead>
<tr>
<th>Color Space</th>
<th>$H_1$</th>
<th>$H_2$</th>
<th>$H_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>RGB</td>
<td>5.8373</td>
<td>5.8172</td>
<td>5.7500</td>
</tr>
<tr>
<td>YIQ</td>
<td>5.8260</td>
<td>5.1581</td>
<td>5.8042</td>
</tr>
<tr>
<td>YUV</td>
<td>5.7981</td>
<td>5.6682</td>
<td>5.8489</td>
</tr>
<tr>
<td>$I_1$ $I_2$ $I_3$</td>
<td>5.8175</td>
<td>5.7108</td>
<td>5.8175</td>
</tr>
<tr>
<td>HSI</td>
<td>4.7890</td>
<td>5.3038</td>
<td>5.8175</td>
</tr>
<tr>
<td>HSV</td>
<td>4.7890</td>
<td>5.3038</td>
<td>5.8338</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Color Space</th>
<th>$H_1$</th>
<th>$H_2$</th>
<th>$H_3$</th>
</tr>
</thead>
<tbody>
<tr>
<td>RGB</td>
<td>5.6993</td>
<td>5.8502</td>
<td>5.8624</td>
</tr>
<tr>
<td>YIQ</td>
<td>5.8426</td>
<td>5.3581</td>
<td>5.9172</td>
</tr>
<tr>
<td>YUV</td>
<td>5.8558</td>
<td>5.9645</td>
<td>5.8147</td>
</tr>
<tr>
<td>$I_1$ $I_2$ $I_3$</td>
<td>5.8426</td>
<td>5.5080</td>
<td>5.3700</td>
</tr>
<tr>
<td>HSI</td>
<td>5.1118</td>
<td>5.7708</td>
<td>5.8426</td>
</tr>
<tr>
<td>HSV</td>
<td>5.1118</td>
<td>5.7708</td>
<td>5.8752</td>
</tr>
</tbody>
</table>

B. Segmentation

Results of segmented aerial images are shown in Fig. 3 and Fig. 4. The top panel of the left column depicts the input image. The segmented objects in the foreground (object 1) or background (object 2) are given in the middle and bottom panel. Pixels belonging to the corresponding object are given in their original color while those outliers are illustrated in black. The middle column illustrates the magnitude of the color space components for the intensity $Y$ and color components $U$, $V$. The right column shows the associated histogram.

The balance of information in the foreground and background objects (denoted as objects 1 and 2 in the figure) is obtained as $(5.35, 5.33)$ in images 1 and $(5.00, 5.02)$ in image 2. In test image 1, the central portion of the image contains the planted field and there are un-planted lands at the top and right-bottom corner. The resultant objects have shown an effective segmentation where the un-planted land is classified as object 1 and the planted field is labeled as object 2. In image 2, there are a number of fields that are planted with different agricultural products showing whiter appearances. The green plants are segmented as object 1 and the other planted fields are segmented as object 2. It is interesting to note that there is no intuitive indications from the shape of the histograms to determine a proper threshold. Segmentation by the entropy-based technique is thus a suggested approach.

V. Conclusion

The study of the effect of the choice of color space representing a color image on the segmentation results has been presented. The result shows that different color spaces carrying different amounts of information content have a biasing effect on entropy-based segmentation approaches. Furthermore, a maximization of total resultant information while balancing between foreground/background information can be achieved by proper segmentation conducted on a single color space. Satisfactory results are obtained from segmenting color aerial images over planted fields, thus verifying the proposed approach.

REFERENCES


Fig. 3. Segmentation result of aerial image - test image 1.

Fig. 4. Segmentation result of aerial image - test image 2.