Analysis of Camera’s Images Influenced by Varying Light Illumination for Design of Color Segmentation

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Cameras are excellent sensors in robotic systems. However, a camera being extremely sensitive to illumination variation restricts its capability. In this paper, color image segmentation of a camera influenced by varying light illumination is studied for extending camera’s capability in the future. The influence of an image captured by camera due to varying light illumination is analyzed. The components of image data represented by colors make the influence of varying light illumination visible for conveniently analyzing. In the analysis, the change rules of the YUV components due to varying illumination is induced to formulate a database consisted of the set of boundaries. Based on the database, an adaptive algorithm for color segmentation against unstable lighting is proposed. The development of the algorithm is summarized by a design procedure. Practical experiments demonstrate the performance of the proposed algorithm. In addition, the adaptive algorithm against uncertain light illumination is included.

Keywords: color segmentation, varying light illumination, image processing, robot vision, adaptive segmentation

1. INTRODUCTION

Cameras are excellent sensors in robotic systems. Service robots and entertainment robots developed as popular products must face the variation of light illumination so that people enjoy life together with robots [1]. Differed from traditional industrial robots, service robots and entertainment robots developed special capability to meet the requirement in a special environment [2]. In human life environment, the light variation makes the camera applied to service robots and entertainment robots difficult. It is crucial to solve the problem of cameras influenced by varying light illumination for bringing robots in our life.

Skin-color segmentation is particularly useful for human postures identified by robots [3-5]. Human motion detection based on dynamic thresholds in image sequences is a necessary skill for robot interaction [6]. However, illumination variation is a big problem for color segmentation in human environment. Skin-color segmentation is solved for video images under the illumination variation including time-varying illumination, multiple sources and single or multiple-colored sources [7]. This function lets robots interact with human more intelligence.

Recent decade, robot competitions such as RoboCup [8] and FIRA [9] become active for promoting robots brought into human life. A dream that a robot soccer team fights against FIFA championship team in 2050 is the main objective of the competitions...
in the future. Nowadays, robot competition activities have become Soccer image analysis is a pre-step of this dream [10]. Robots playing soccer in outdoor environment are crucial capability against human [11]. Kulessa and Hoch presented the method of the illumination conditions detected for improving the performance of color segmentation algorithm [12]. Li et al. proposed an adaptive color segmentation algorithm based on self-organizing map and supervised learning to make the algorithm robust [13]. The use of camera against varying light illumination becomes the main challenge of soccer robot against human.

Therefore, this paper is devoted to studying color image segmentation against varying light illumination. In this study, an environment to grab empirical picture data for analyzing colors influenced by varying illumination is formulated. For easily analyzing a large amount of empirical image data, the values of YUV components are expressed as colors. Based on the analysis of the empirical image data, the sets of boundaries for color segmentation consist of a database used in an adaptive algorithm proposed against varying light illumination. In special, the average value of the color blob’s Y component plays as the index corresponded with its boundary set for searching in the database. The adaptive algorithm against varying light illumination is demonstrated by practical experiments.

The main contribution of this paper is to make the adaptive algorithm robust in the light illumination switched between extremely distinct situations. The adaptive algorithm proposed by Li et al. [13] is only against the illumination conditions in little varying. In this research, four light illumination situations exact test the proposed algorithm. This exact testing demonstrates that this algorithm is useful in the nature environment like human life. The results of this research pave a way towards the dream of RoboCup 2050.

The rest of this paper is organized as follows. In section 2, the fundament of color segmentation is constructed, and two definitions for solving color segmentation are given. The colored blobs influenced by varying light illumination are analyzed to point out the problem of color segmentation in section 3. Section 4 is the adaptive color segmentation algorithm designed against varying light illumination. Practical experiments are finished in section 5. Finally, conclusions are given in section 6.

2. PRELIMINARIES

Colors of an object image result from its reflective rays. Only visible rays reflected from an object consist of image colors we see. R (red), G (Green) and B (blue) can not only be distinguished easily by obviously distinct wavelengths, but be also combined to build a variety of colors for many display devices.

Although the RGB color space is suitable for color display, the high correlation among R, G and B components makes color analysis and segmentation difficult. For instance, one color in different light illumination will possibly result in extremely different values of R, G and B components. Therefore, various color spaces such as HSI (Hue-Saturation-Intensity), HSV (Hue-Saturation-Value), YIQ and YUV etc. are developed for various objectives of color image usage. For example, YIQ and YUV are TV signals defined for American and European systems, respectively. However, none of the color spaces can dominate the others for all kinds of color images.
YUV related to the RGB color space have the following linear transformations:

\[
\begin{bmatrix}
Y \\
U \\
V
\end{bmatrix} = 
\begin{bmatrix}
0.299 & 0.587 & 0.114 \\
-0.169 & -0.331 & 0.500 \\
0.500 & -0.419 & -0.081
\end{bmatrix}
\begin{bmatrix}
R \\
G \\
B
\end{bmatrix},
\]

(1)

where \(0 \leq R \leq 1\), \(0 \leq G \leq 1\), and \(0 \leq B \leq 1\). In the YUV color space, the Y component is a measure of the color, and is a possible candidate for edge detection in color image. The U and V components jointly describe the hue and saturation of image colors. The YUV space can partly get rid of the correction of the R, G and B components in an image.

The linear transformation used for the color spaces YUV spends less computation time than the nonlinear HIS and HSV. Besides, some digital cameras which render picture data in the YUV color system don’t need these transformations. Such cameras are selected for the study. Therefore, in this paper, the strategy based on the YUV color space is proposed for quick color segmentation.

The U and V components in the YUV color space jointly contain the hue and saturation of image colors. In this paper, U and V concerned with hue and saturation have the following equations:

\[
H_{YUV} = \tan^{-1}\left(\frac{V}{U}\right),
\]

(2)

\[
S_{YUV} = \left(V^2 + U^2\right)^{1/2}.
\]

(3)

\(H_{YUV}\) value like \(H\) in HSI owns the characteristic of color information, and \(S_{YUV}\) is the measure of the amount of rays. Fig. 1 shows some colors represented by the color system of Y, \(S_{YUV}\) and \(H_{YUV}\). In this paper, Y, \(H_{YUV}\) and \(S_{YUV}\) influenced by varying light illumination are analyzed by experiments.

![Fig. 1. The YUV color space represented by luminance, saturation and hue.](image-url)
This research tries to solve the problem of robotics soccer competition situation automatically identified by cameras. For the last decade, the robotics soccer system competition such as RoboCup [8] and FIRA [9] is tremendously grown up to pursuit a dream that a team of soccer robots fights against the championship team of FIFA in 2050. This dream must face the problem of the competition situation identified by cameras in the nature environment that it is possible to vary light illumination. For automatic identification, the color blobs easily distinguished each other are usually pasted on the robots during competition.

Fig. 2 shows a team of robotics soccer for RoboCup in small-size league [14]. In the small-size league, a camera hanged on the top of the field center grabs the image during the competition. By image processing, the competition situations are identified for the decision making of artificial intelligence. The robots are usually pasted by distinguishable color blobs for conveniently image processing. Six color blobs, Orange (O), Blue (B), Yellow (Y), Cyan (C), Magenta (M) and White (W), easily distinguished in color coordinate system are usually used in the competition. They are usually pasted on the top of the robots as shown in Fig. 2. In the competitions of RoboCup and FIRA, identifying the colored blobs serves for localizing the position and orientation of the robots. In this paper, the experimental study thus focuses on the segmentation of these six colored blobs. Experimental results not only reveal how varying light illumination influences the components in YUV color space, but also summarize the variation to build a database used to design an adaptive algorithm for color segmentation against varying lighting.

In the following, there are two definitions used to develop algorithms for color segmentation.

**Definition 1** Threshold boundaries of a colored blob.

A pixel is identified as a color, if the YUV components, $y$, $u$ and $v$, of the pixel satisfy:

$$y_l < y < y_u, \quad u_l < u < u_u, \quad v_l < v < v_u$$

(4)
where \( y_l, u_l \) and \( v_l \) are the lower boundaries of the YUV components of the identified color, respectively, and \( y_u, u_u \) and \( v_u \) are the upper boundaries, respectively. It is necessary to find the upper and lower boundaries of the pixels belonged to a color for segmentation. Fig. 3 illustrates the boundaries of yellow color.

**Definition 2**  
The average values of the YUV components of a colored blob.

Let a colored blob have a cluster of same color pixels, and let the YUV components of the \( j \)th pixel in the colored blob be \( y_j, u_j \) and \( v_j \), respectively. Then the average values of the colored blob are defined as

\[
y = \frac{\sum_{j=1}^{n} y_j}{n}, \quad u = \frac{\sum_{j=1}^{n} u_j}{n}, \quad v = \frac{\sum_{j=1}^{n} v_j}{n},
\]

where \( n \) is the number of the pixels in the colored blob.

The average values of the YUV components of a colored blob are useful for analyzing a color image influenced by varying light illumination, and will be used to judge the light illumination during capturing an image.

3. ANALYSIS OF COLORED BLOBS INFLUENCED BY VARYING LIGHT ILLUMINATION

The image sensor of a camera has extremely high sensitivity to varying light illumination. Human eyes automatically adjust iris to capture rays for consistent illumination, but the image sensor in a camera usually results in inconsistent color data due to little illumination variation because of fixed aperture. Varying illumination from light source surely makes captured image data different. In this paper, an environment is organized to study the varying of light illumination how to influence color data captured by the image sensor of a camera.

In order to build the environment that can vary light illumination, there are two kinds of light sources, fluorescent and sunshine lamps, hanged on the top of the scene as shown in Fig. 4. There are four fluorescent lamps (60 Watt per lamp) for uniform lighting up the environment, but there are two sunshine lamps (500 Watt per lamp) handed on the left and right of the scene for resulting in non-uniform light illumination. In Fig. 4, the left sunshine lamp is lighting, but the right one is turned off. Notice that the lamps and the camera used in the study are the normal consumer products used in our living. Although the picture of robotic soccer field as shown in Fig. 5 is unclear, color segmentation in such environment is the need of robots designed for living with human in the future. At present, RoboCup and FIRA federations often force participators to develop the algorithms of color segmentation for the nature environment like this.

The designed lighting consists of three situations: (a) Lighting all fluorescent lamps, (b) Lighting all fluorescent lamps and right sunshine lamp and (c) Lighting all fluorescent lamps and two sunshine lamps. As a result, situations (a), (b) and (c) have 240-watt, 740-watt and 1240-watt light sources, respectively. In this study, we measure and store the YUV components of color image in situations (a), (b) and (c), respectively. Another lighting situation, named situation (d), is lighting all fluorescent lamps and left sunshine
lamp. The YUV components during situation (d) are not measured to regard as the uncertainty of light illumination for testing the robust of the developed algorithm.

Even if all fluorescent lamps are lighted up, the picture of the scene as shown in Fig. 5 is extremely non-uniform. Such lighting situation is possible in RoboCup competition. To solve the non-uniform light illumination, the scene is divided into sixteen regions as shown in Fig. 5. The algorithm for color segmentation is developed for every region in the scene. Hence, the following definition will be used to distinguish the parameters of each region.

**Definition 3** Regional parameters.

There are sixteen regions in the scene. The YUV components of the $m$th region are $y^m$, $u^m$ and $v^m$, for $m = 1, \ldots, 16$.

Accordingly, the average values of the colored blobs in the $m$th region are $y^m_\text{avg}$, $u^m_\text{avg}$, and $v^m_\text{avg}$, for $m = 1, \ldots, 16$.

In order to obviously show how the light illumination influences the components $Y$, $U$, $V$, $H_{YUV}$ and $S_{YUV}$ in a picture, Table 1 defines their value ranges as colors. Therefore, the values of YUV components of the scene picture influenced by varying light illumination can be easily expressed by colored pictures like Fig. 6. Figs. 6 (a)-(c) shows the $Y$ values as lighting in situations (a), (b) and (c), respectively. It is obvious that the centers of Figs. 6 (a)-(c) change the colors from blue to orange whose value levels are from 4...
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Fig. 6. La Y values mostrada por las imágenes de color en las situaciones (a), (b) y (c).

Table 1. The Colors defined representing Y, U, V, S_{YUV}, and H_{YUV} values.

<table>
<thead>
<tr>
<th>Level</th>
<th>Y · U · V · S_{YUV}</th>
<th>H_{YUV}</th>
<th>Represented colors</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0 – 15</td>
<td>0 – 23</td>
<td>RED</td>
</tr>
<tr>
<td>1</td>
<td>16 – 31</td>
<td>24 – 47</td>
<td>INDIGO</td>
</tr>
<tr>
<td>2</td>
<td>32 – 47</td>
<td>48 – 71</td>
<td>YELLOW</td>
</tr>
<tr>
<td>3</td>
<td>48 – 65</td>
<td>72 – 95</td>
<td>DARKGREEN</td>
</tr>
<tr>
<td>4</td>
<td>64 – 79</td>
<td>96 – 119</td>
<td>BLUE</td>
</tr>
<tr>
<td>5</td>
<td>80 – 95</td>
<td>120 – 143</td>
<td>ORANGE</td>
</tr>
<tr>
<td>6</td>
<td>96 – 111</td>
<td>144 – 167</td>
<td>PURPLE</td>
</tr>
<tr>
<td>7</td>
<td>112 – 127</td>
<td>168 – 191</td>
<td>CYAN</td>
</tr>
<tr>
<td>8</td>
<td>128 – 143</td>
<td>192 – 215</td>
<td>MAGENTA</td>
</tr>
<tr>
<td>9</td>
<td>144 – 159</td>
<td>216 – 239</td>
<td>LIGHTGREEN</td>
</tr>
<tr>
<td>10</td>
<td>160 – 175</td>
<td>240 – 263</td>
<td>BROWN</td>
</tr>
<tr>
<td>11</td>
<td>176 – 191</td>
<td>264 – 287</td>
<td>LIGHTRED</td>
</tr>
<tr>
<td>12</td>
<td>192 – 207</td>
<td>288 – 311</td>
<td>GRAY</td>
</tr>
<tr>
<td>13</td>
<td>208 – 223</td>
<td>312 – 335</td>
<td>LIGHTYELLOW</td>
</tr>
<tr>
<td>14</td>
<td>224 – 239</td>
<td>336 – 359</td>
<td>BLACK</td>
</tr>
<tr>
<td>15</td>
<td>240 – 255</td>
<td></td>
<td>WHITE</td>
</tr>
</tbody>
</table>

(64 – 79) to 5 (80 – 95). The YUV values shown by the colored pictures easily observe the influence of varying light illumination.

The analysis of the colored blobs influenced by varying light illumination exactly measures the change of YUV components’ boundaries. The algorithm shown in Fig. 7 finds the sets of boundaries of the colored blobs. Whether the colored blobs in a picture are identified or not can easily show their pixels with the identified colors (O, B, Y, C, M, W) or original colors. In normal light illumination, the colored blobs are identified by the default sets of the YUV components’ boundaries. As the percentage of the identified pixels in the colored blob is not enough 80%, the sets of the YUV components’ boundaries are adjusted. It is well known that the stronger light illumination, the higher Y component value. The adjustment of the boundaries is thus according to the value of Y component. In Fig. 7, the left column adjusts the boundaries of the YUV components for larger Y value, but the right column for smaller Y value.
In combination with the YUV components represented by Table 1, the ranges of YUV components can be observed by experiments easily. In the experiments, the operation of picture data shown by colorful pixels also has the function of region enlargement to let us easily read the range of the Y, U and V components. By the experiments, Figs. 8-10 show the Y, S_{YUV} and H_{YUV} components of six colored blobs under light situations (a), (b) and (c), respectively.

The ranges of Y components in various lighting situations are shown in Fig. 8. Because there are sixteen regions separated for solving no-uniform light illumination in the environment of large space, Fig. 8 is only for region 1 to briefly present the influence of varying light illumination. There are six colors listed in Fig. 8 for comparing. As shown in Fig. 8, the Y values increase as intensifying light illumination. In addition to Y components, the ranges of U and V components influenced by varying light illumination are also measured, but absent to show because their change is unregulated. Instead, the ranges of H_{YUV} and S_{YUV}, are shown in Figs. 9 and 10 for studying. As shown in Fig. 9, the ranges of H_{YUV} values result in less change due to varying light illumination. For example, yellow, cyan and magenta colors have one level change, but orange and blue colors are of no change. However, white has unregulated change because its hue is extremely sensitive to light illumination. Furthermore, the ranges of S_{YUV} values have regular change...
Fig. 8. The Y ranges of various colors as lighting up in situations (a), (b) and (c).

Fig. 9. The H_{YUV} ranges of various colors as lighting up in situations (a), (b) and (c).
due to varying light illumination. To summarize, the ranges of $H_{YUV}$ and $S_{YUV}$ change as shown in Figs. 9 and 10 are useful to develop color segmentation strategy for solving the lighting situation in varying light illumination. In addition to region 1, the rest of fifteen regions do such analysis for the boundaries of the $Y$, $H_{YUV}$ and $S_{YUV}$ components of the colored blobs. All the boundaries are used to develop the adaptive algorithm in next section.
4. AN ADAPTIVE ALGORITHM FOR COLOR SEGMENTATION

Under lighting in different illumination, the YUV components of a picture are of different values. Hence, varying light illumination will result in that the original boundaries are unsuitable for segmenting colored blobs. In this paper, a database consisted of the sets of boundaries for color segmentation is constructed against varying light illumination.

The database is built under three light situations (a), (b) and (c). There are thus three sets of boundaries in the database, including \( Y_{i,a}^{n,m} \), \( Y_{i,b}^{n,m} \), \( Y_{i,c}^{n,m} \), \( H_{i,a}^{n,m} \), \( H_{i,b}^{n,m} \), \( S_{i,a}^{n,m} \), and \( S_{i,b}^{n,m} \), in which \( i = a, b, c \) represents the light situations, \( n \) stands for colors O, B, Y, C, M, or W, and \( m = 1, \ldots, 16 \), stands for the regions in the field. In this paper, the adaptive algorithm is designed to select appropriate set of boundaries for identifying colored blobs against varying light illumination.

However, it is difficult to judge that which boundary set is appropriate for color segmentation in a light situation right now. The average values of the Y component in color \( n \), region \( m \), and light situation \( i \), \( y_{i,n}^{m} \), plays the role as the index of the boundary set in the database. As missing identifying color \( n \) in lighting situation \( i \) and region \( m \), the Y component of the captured image is compared with the other \( y_{i,n}^{m} \) in the database for the appropriate boundary set. The set of boundaries whose \( y_{i,n}^{m} \) is most approach the Y component of the captured image is regarded as appropriate one.

Missing identifying a colored blob is defined as the percentage of its identified pixels is less than 80%. Because a picture captured by an image sensor is a random process system, it is possible to miss identifying a colored blob in the same light illumination. That will lead to frequently change the set of boundaries in the same light illumination, if replacing immediately does as missing identifying. In addition, the light situation switched by turning sunshine lamps on or off cannot result in stable illumination immediately. In order to let the light situation be of enough time in stable illumination, the condition of replacing the boundary set is defined by five times of missing identifying a colored blob. If the image processing of one frame needs 100ms, five times of missing identifying one colored blob wastes 500 ms. Such time is enough to let light illumination in stable situation as turning on or off the lamps.

As the percentage of the identified pixels over 80%, the set of boundaries is continuously used for segmenting. If the percentage of the identified pixels happens five times less than 80%, the set of boundaries is replaced according to the comparison between the Y component of the segmented pixel and \( y_{i,n}^{m} \) of other sets. Fig. 11 is the adaptive algorithm for color segmentation against varying light illumination. In Fig. 11, five times of missing identifying a color blob change the old set of boundaries, but the new set is replaced as three times of missing identifying.

The development of color segmentation against varying light illumination is summarized by the following design procedure:

1. Find the various sets of boundaries due to various situations of light illumination by the procedure presented in Fig. 7;
2. Calculate \( y_{i,n}^{m} \) accompanied with the found sets of boundaries to build the complete database;
3. Use the adaptive algorithm presented as Fig. 11 for color segmentation.
Fig. 11. The adaptive algorithm of color segmentation against varying light illumination.

5. EXPERIMENTAL RESULTS

There are two kinds of experiments to demonstrate the adaptive algorithm. The first kind is the light situations switched between lowest (situation (a)) and highest (situation (c)) illumination. The light situations (a) and (c) have extremely distinct Y component so that their sets of boundaries are distinguishable obviously. The second kind is the light situations switched to an unmeasured illumination (i.e. light situation (d)) for testing the robust of the adaptive algorithm against uncertain light illumination.

All the experiments begin at its original lighting situation. During the colored blobs stably identified by the algorithm, the lighting situation is switched into the other. In the experiments, the time of missing identifying the colored blobs is defined at the tenth frame in the image processing. That is the adaptive algorithm only stores the identifying results of ten image frames before missing identifying. In addition, the history of the adaptive algorithm includes the identifying results after missing identifying.

Figs. 12 and 13 show the first kind experiments that switch the lighting between lowest and highest illumination. In these Figs., horizontal axis is the number of image frame during segmenting, but vertical axis is the ratio of identified pixels. The identified ratios of sixes color blobs are shown by their colors in different shape markers noted on the right-bottom location of these figures. For the sake of simplification, the figures of experiments only show the results of regions 1, 4 and 12 for representing the field in center, left and right, respectively. As shown in these figures., in the initial segmentation, the identified ratio is over 0.8 in normal. It is no longer over 0.8 at the tenth frame as
changing the light situation. However, at the fifteenth frame, five frames after changing the light situation, the adaptive algorithm retrieves in normal segmentation, the identified ratio over 0.8. The experimental results shown in Figs. 12 and 13 demonstrate that the adaptive algorithm solves the problem of the lighting switched between the lowest and highest illumination.

The period of turning lamps on or off in stable light illumination is uncertain. The time of this period includes that of a colored target heated at stable color temperature by the sunshine lamps and grabbed by the image sensor. Many complicated factors affects on this time period. The experiments show five times of missing identifying the color blobs about wasting 500 ms is enough for grabbing stable image data.

The experimental results shown in Figs. 14 and 15 are the lighting switched between measured and unmeasured illumination. These experiments examine the algorithm adaptive in uncertain light situation. As shown in Figs. 14 and 15, the identified ratio becomes less 0.8 at the tenth frame, the lighting change. After five frames, the identified ratio becomes over 0.8 again because the adaptive algorithm finds appropriate boundary set. These experiment results demonstrate that the adaptive algorithm can overcome uncertain lighting situation.

![Fig. 12. Light situations switched from (a) to (c).](image1)

![Fig. 13. Light situations switched from (c) to (a).](image2)

![Fig. 14. Light situation (a) switched to (d).](image3)

![Fig. 15. Light situation (c) switched to (d).](image4)
5. CONCLUSIONS

In this paper, the adaptive algorithm against varying light illumination for color segmentation is proposed. The algorithm is based on a database built by the sets of boundaries according to experiments in various light illumination. Specially, in the database, $y^m_n$, the average of the Y components of color $n$ at region $m$, are adopted to select the appropriate set of boundary. Practical experiments demonstrate the performance of the adaptive algorithm. Two lighting source, fluorescent and sunshine lamps, used in this study used in this study imply that the adaptive algorithm is suitable for various lighting source. The experiments for uncertain light illumination provide strong evidence to present that the adaptive algorithm can be extended for bad light illumination.

Image data is huge context information. It is hard to analyze for color segmentation. Varying lighting make the components of image data more complicated to understand. In this paper, the components of image data shown by color make the influence of varying lighting visible. It becomes easy to analyze image data to construct a database against varying light illumination.

In human life, irregular illumination is a normal situation. A camera used for either service robots or entertainment robots must face the problem arisen by this situation, if designers want to bring them into human life. The adaptive algorithm paves a way to boost the capability of cameras and to develop them as a main component of robotic systems.

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