A Vision-Based Navigation Robot System Using Hybrid Color Models

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Abstract. Vision-based navigation robot system is a hot issue in the fields of robot vision and control system. As the development of image processing technique, the application of vision-based navigation robot system is increasing in household and industrial robots. This paper designs a navigation system based on robot vision named Patio2, using hybrid color models including white balance, color detection, and connect domain building. With necessary experimental verification, the developed system can find the color square efficiently, walk towards the right direction, and stop in a certain area with limited distance of 10cm.

1. Introduction

Vision is the sense that enables us, humans, to extract information about the physical world, and, appropriately, it is the sense that humans rely on the most. In recent past, computer vision techniques capable of extracting such information are continuously being developed and refined. Vision processing is computationally intensive, but as faster and lower priced processors being developed, the development of real-time vision-based navigation systems for mobile robots is becoming a reality for a variety of complicated jobs and more research works are being focused in this domain now, than ever before.
In this paper, we present a highly efficient method for robots to find and reach color squares which are red, green and blue by using the color space model HSV (Hue, Saturation, Value) discovered by A. R. Smith in 1978. This team design project aimed to complete 2 tasks on patio 1 and 2 via a robot car. In order to achieve the goals, 6 main functions were designed, including Line Tracing, Colour Recognition, Geo-magnetic Navigation, Communication, Feeding and Ultrasonic Distance Detection. The robot would trace the middle horizontal line which always passing through the geometric center calculated from the color squares after binarization.

This paper presents the system design and applications of hybrid color model for a vision-based navigation robot system and a general framework of the system is shown in Fig. 1 and Fig. 2. In Section 2, the procedure of Patio2 in experiments are introduced briefly. Section 3, Section 4 and Section 5 describe the methods of color recognition and applications. The conclusion is presented in Section 6.

2. Procedure of the Navigation Patio2 System
The flowchart of the patio 2 can be summarized as follows. We successfully test the proceeding theoretical descriptions in the field.
2.1. Navigation to the First Color Lump
Firstly, the car starts from the starting point and we guide the car by geo-magnetic-aided navigation towards the direction of the first color lump.

![Figure 4. Navigation to the first color lump (a) and the specific color lump (b).](image)

2.2. Navigation to the Specific Color Lump
Before the color lump comes into the camera’s view, we use geo-magnetic navigation. After that, color recognition algorithm, as we have covered before, starts to detect the color of the first color lump. Specifically, we calculate the area of each three color channel and the color with the largest area will be the color in front of the car. The car will stop after going across the color lump. Then the car will go in the direction as what it has been preset.

3. Hybrid Color Models for the System
3.1. While Balance
An object may appear different in color when it is illuminated with different light sources because of the color temperature difference of the light sources, which induces the shift of the reflection spectrum of the object from the original color. Hu-man eyes cannot distinguish this difference, yet for an recording equipment the shift of light spectrum may be recorded if the light is not standard enough [1].

Several aspects of the acquisition and display process render such conversion essential, which includes the fact that the dynamic response of the acquisition sensors does not match that of the human eye [2]. White balance is a common practice in photograph or image processing to compensate for the ambient light, which performs adjustment of the intensities of the colors, i.e., red, green, and blue primary colors, for a given image. The main objective of this adjustment is to render the neutral colors so that color casts due to the ambient light are removed[11].

(1) Firstly we need to average gray level of the image and it is calculated as
\[
\text{Gray} = \frac{R+G+B}{3}
\]  

(2) Then we calculate the weight of three color channel
\[
k_r = \frac{\text{Gray}}{R}, k_g = \frac{\text{Gray}}{G}, k_b = \frac{\text{Gray}}{B}
\]

(3) Adjust each component of \(R, G, B\) for every pixel
\[
C(R') = C(R) * k_r, \quad C(G') = C(G) * k_g, \quad C(B') = C(B) * k_b
\]
3.2. Color Detection
As shown in Fig. 6, the basic idea is based on the HVS [4][5](hue saturation value) which is one of the most common cylindrical-coordinate representations of points in an RGB color model. It rearrange the geometry of RGB in an attempt to be more intuitive and perceptually relevant than the Cartesian (cube) representation. The reason for choosing HSV color space model is that RGB model cannot reveal the specific color information such as how bright it is, what the color is and how is the saturation, while HSV model could help us to set the threshold value straightforwardly. The converting relationship from RGB to HSV is shown as follows.

\[
V = \text{Max}(R, G, B) \tag{4}
\]
\[
S = \frac{V - \text{Min}(R, G, B)}{V} \tag{5}
\]
\[
H = \begin{cases} 
\frac{60(G-B)}{V - \text{Min}(R, G, B)} & \text{if } V = R \\
\frac{(20+60(G-B))}{V - \text{Min}(R, G, B)} & \text{if } V = G \\
\frac{20+60(R-B)}{V - \text{Min}(R, G, B)} & \text{if } V = B 
\end{cases} \tag{6}
\]

Where if \(H<0\) then \(H=H+360\). The outputs are \(0 \leq V \leq 1.0 \leq S \leq 1.0 \leq H \leq 360\). The matrix has been resized to 680×480 for further process. The further step is to convert RGB value (each pixel has 3 component RGB) to a HSV space color model. Since we care about the three components \(H\), \(S\) and \(V\), the Histogram Equalization process was applied to increase the contrast. Then, the image was segmented by specific threshold values converting to a binary image which contains the color square [6]. After the image transferred to HSV color Space model, then using the threshold we could easily get the threshold graph contains R, G and B 3 colors square [7], illustrated in Fig. 7.
Figure 6. Flowchart of the proposed color detection model.

Table 1. Threshold values for color squares based on HSV model (the range for H, at raspberry pi is 0-180, while S, V ranges from 0-255).

|       | Hue   | Saturation | Value  |
|-------|-------|------------|--------|
| Rmin  | 0.7   | 126        | 0.35   | 89.25  | 0.35 | 89.25 |
| Rmax  | 0.86  | 154.8      | 1      | 255    | 1    | 255   |
| Gmin  | 0.16  | 28.8       | 0.18   | 45.9   | 0.18 | 45.9  |
| Gmax  | 0.28  | 50.4       | 1      | 255    | 1    | 255   |
| Bmin  | 0.5   | 90         | 0.5    | 127.5  | 0.4  | 102   |
| Bmax  | 0.7   | 126        | 1      | 255    | 1    | 255   |

Figure 7. The image of original experimental scene (a), and images before (b) and after (c) color detection process.

4. Connect Domain Building
The flowchart of connect domain building is shown in Fig. 8. In the binary image the sets of adjacent
points forms connected domain [8]. Basically, there are two types connected domain in Fig. 9(a) and Fig. 9(b), 4 adjacent connected domain and 8- adjacent connected domain. What needed to process is to get the structure element of the image, a function in OpenCV [3, 6] has been applied. “GetStructuringElement” function is applied to define structure element, and in this project the element is a rectangular with the size $4 \times 4$. After that, open operation and close operation in morphology. Open stands for and dilating and eroding which could disconnect the narrow connection and smooth the outline.

As shown in Fig. 10, open operation stands for eroding and dilating, which can do the fill up the connected line while also smooth the outline. The reason for that is it could decrease the disconnection line in the inner graph and irreverent information. Then there are three times scanning process, the first scanning is to mark the connected domain with numbers from 254 to 1 using the flood fill method [10]. Second, calculate the amount of each color and find the maximum color domain, and finally set the maximum color domain to be 255 while set others to 0 then output. The image results of maximum value are shown in Fig. 11.
5. Color Center Estimation

The processing above presents a threshold pattern without noisy snowflakes. Problem left for the color tile guided navigation is to determine the relative position of the tile, which is considered as the target in this subroutine, with respect to our robot. This relative location includes two components: angle between tile and the current moving direction, and distance to the tile. Both of the two factors can be estimated with the pre-processed binary image, making use of the center coordinates of the pattern valued “1”.

To fix moving direction of the robot, angle is evaluated with how much Y coordinate of the center deviates from midpoint in the frame. This difference of Y value is exported as a feedback to the controller by function “midpoint” and thus fixes the direction. When the robot is close enough to the tile, it should be able to stop going ahead and do the following tasks instead, which requires an estimation of the distance to the tile. Without an emphasis on precision of the distance, in our program this process is implemented by testing the X coordinate of the center, if it is within bottom 1/4 of the frame, the robot is expected to be close to the tile and a “stop” subroutine is triggered to slow the vehicle down till it moves above the tile.

6. Conclusion

Robot vision as a basic component of machine learning, is widely used in the navigation robot system. In this paper, we have designed and developed a navigation system based robot vision termed Patio2, using hybrid color models including with white balance, color detection, and connect domain building. The developed system accomplished the function of finding color square efficiently, walking towards the right direction, and stopping in a certain area with limited distance of 10cm. In future, we need further the precision of detection leading to search the desired square at a long distance.

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