Improvement of Color Recognition Using Colored Objects

T. Kikuchi[1], K. Umeda[1], R. Ueda[2], Y. Jitsukawa[2], H. Osumi[1], and T. Arai[2]

[1] Chuo University, 1-13-27 Kasuga, Bunkyo-ku, Tokyo, Japan,
tkikuchi@sensor.mech.chuo-u.ac.jp, {umeda,osumi}@mech.chuo-u.ac.jp,
WWW home page: http://www.mech.chuo-u.ac.jp/umedalab/index_e.html
[2] The University of Tokyo, 7-3-1 Hongo, Bunkyo-ku, Tokyo, Japan,
{ueda,jitsukawa,arai-tamio}@prince.pe.u-tokyo.ac.jp,
WWW home page: http://www.arai.pe.u-tokyo.ac.jp/

Abstract. Recognition of colored objects is important and practical for robot vision. This paper proposes a color recognition method which is robust to illumination change. A color space of Cb/Y and Cr/Y is introduced where Cb and Cr are color difference and Y is intensity of YCbCr color space. This color space is not affected by the change of the brightness of illumination. And a method to update clusters of color table is proposed. The method can cope with the change of the color of illumination. Experiments show that the proposed method can recognize color more robustly for illumination change. RoboCup four legged robot league is chosen as the research platform.

1 Introduction

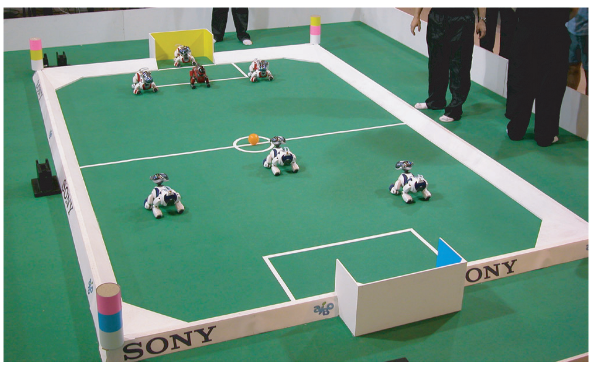
Images are widely used by a robot to recognize its environment. Many objects in the environment where a robot works have some colors and they are useful cues for recognizing the environment or objects. Color information observed in images changes according to illumination condition and thus robust object recognition with color information is not easy. Many studies have dealt with the estimation of illumination or object color [1][2].

To recognize color fast and simply, a lookup table that relates observed pixels and color names is effective. Jüngel et al. proposed a method to construct a table dynamically by scanning an image for the RoboCup field [3]. Mayer et al. assumed a known environment to find a target object with a given color table and modify the table [4]. These methods are not applicable to general environment because of the restriction of the environment for constructing their recognition method. Hanek et al. utilized shape information instead of color information for object recognition in RoboCup middle size league [5]. Their method requires much calculation cost. Dahm et al. proposed a new color space in which color clustering becomes simpler [6].

We propose a new method to recognize colored objects robustly. A color space which is simple and robust for illumination change is introduced. A color table is updated using statistical information of original color cluster and observed pixels. The effectiveness of the proposed methods are verified experimentally. RoboCup four legged robot league is chosen as the research platform.

2 Camera and Environment

Sony ERS-7 (AIBO) is the common robot for RoboCup four legged robot league. A CMOS camera is mounted at its nose and used for image acquisition. The image size is small, 208 $\times$ 160 pixels . Its color space is YCbCr. A 4200 mm $\times$ 2700 mm field is used for the match. Objects in the field are a ball, goals, robots, landmarks and the field itself as shown in Fig. 1. They are colored to help autonomous behaviors of the robots. It is obvious that color reconition is fundamental for tasks as self-localization, measurement of ball position, etc.



Ball	Orange
Goal	Sky blue, Yellow
Field	Green, White
Robot	Red, Dark blue
Landmark	Pink-Sky blue, Pink-Yellow

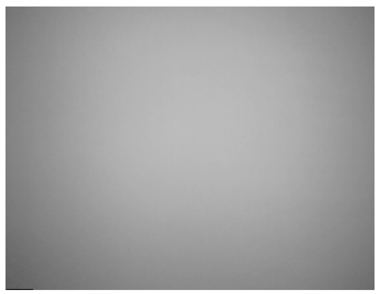
Fig. 1. Field of RoboCup four legged robot league

3 Camera Calibration

Proper camera calibration is essential for measurement with images. Camera parameters to calibrate are, intrinsic parameters such as focal length [7], distortion of the lens, limb darkening etc.

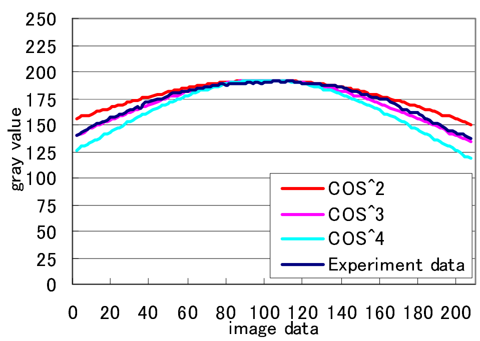
We took advantage of the calibration function of MVTec Halcon image processing software [8] to obtain intrinsic and distortion parameters. The distortion parameter κ is -4683m^{-2}, which is smaller than we expected, and we found that correction of distortion is not mandatory for image processing with the camera.

Image intensity becomes darker at the limb, and it is called limb darkening (or vignetting). Theoretically, it is proportional to the fourth power of cosine of irradiation angle. Fig. 2(a) shows the image of a white drawing paper parallel to the camera. The limb darkening is obviously observed because the lens is wide-angle (56.9deg $\times$ 45.2deg). Fig. 2(b) shows the intensity values for a row of image. We can see the limb darkening of the ERS-7's camera is proportional to the third power of cosine, not fourth. Fig. 2(c) shows the compensation by the third power of cosine. Uniform intensity distribution is obtained. However, compensation of the limb darkening is not mandatory either, for we utilize a color space robust to the brightness change.



(a) Original image with limb darkening

(c) Compensated image



(b) Limb darkening for a row of image

Fig. 2. Limb darkening of ERS-7 CMOS camera and its compensation

4 Realization of Robust Color Table

4.1 Color Table

In real-time image processing, object recognition with a color image is often realized based on color labeling. Color labeling here means to relate each observed pixel to an object's color name such as the ball color. It is realized by thresholding in a color space or by using a lookup table (color table) that relates each pixel to a color name. We take advantage of the color table for color labeling. The table-based method has the characteristics of detailed color labeling with low calculation cost.

4.2 Color Space Robust to Brightness Change

The color space of the ERS-7's camera is YCbCr as mentioned above. Y, Cb and Cr represent intensity and color difference of blue and red respectively. For color recognition, Cb and Cr are important. In principle, Cb and Cr change in proportion to the Y, i.e. Cb and Cr are affected by brightness. Therefore, we propose a color space of the color differences divided by the intensity; Cb/Y-Cr/Y space. Color table is constructed and recognition is performed in the space.

This space is expected to be robust to the brightness change. Fig. 3 shows an example. A Kodak color chart was captured by the camera, and each pixel value is plotted in Cb-Cr space and Cb/Y-Cr/Y space. Pink, yellow and green data of the chart were tested. In Fig. 3, data with suffix "b" and "d" were captured at bright (1200 lx) and dark (800 lx) environment respectively. We can see that the Cb/Y-Cr/Y space is not affected by the brightness change. Additionally, we can see distributions for the dark image tend to become larger. It is because the effect of noise of the intensity value is magnified by the division.

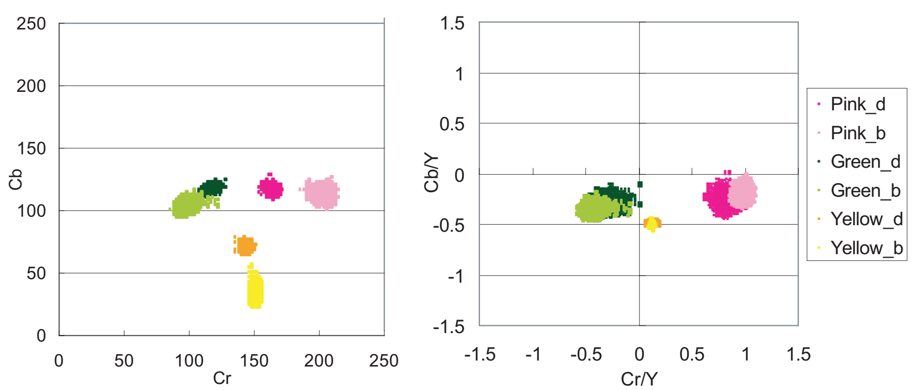


Fig. 3. Color disribution of Cb-Cr space and Cb/Y-Cr/Y space

4.3 Update of Color Table

When illumination changes, observed color information also changes. We propose a method to cope with the color change to some extent. The basic idea is to update the color table according to the illumination change.

Fig. 4 outlines the update process. Suppose a reference color table was acquired in advance and average vector and covariance matrix of each cluster of the color table is calculated as shown in Fig. 4(a). The ellipses represents the points with the same Mahalanobis distance.

The update process of the color table is as follows.

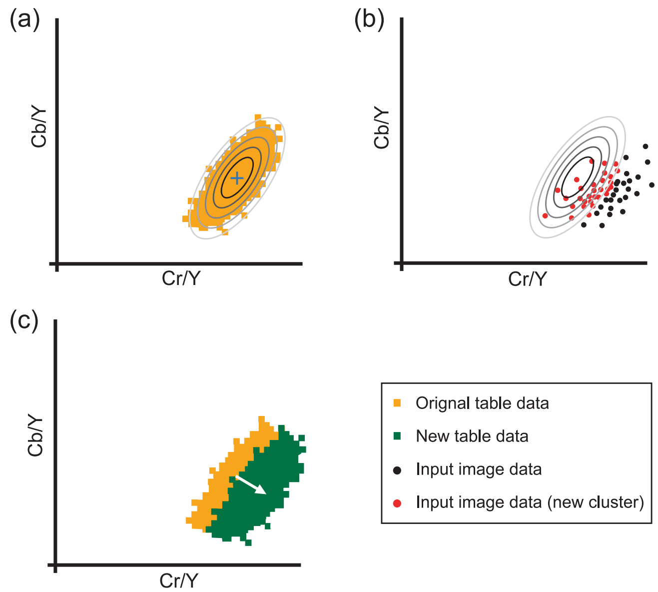


Fig. 4. Update of color recognition table

1. Capture an image under an illumination condition and plot each pixels of the image on Cb/Y-Cr/Y space.
2. Make a cluster with points which have small Mahalanobis distance to the cluster of the color table as shown in Fig. 4(b). The square of Mahalanobis distance obeys the χ^2 distribution with 2 degrees of freedom and statistical evaluation is possible.
3. Calculate the offset between the cluster made in 2 and the cluster of the color table.
4. Move the the cluster of the color table by the offset calculated in 3 and make a new cluster of the color table（Fig. 4 (c)）

By applying the above procedure to each cluster of the color table, an updated color table is constructed.

5 Experiments

The lighting was by commercially available fluorecent lights. They were adjusted to 1200 and 800 lx.

5.1 Color Recognition Experiments

First we constructed the reference color table in advance under the 1200 lx illumination. Three images were used for this. For comparison, we prepared a traditional color table in YCbCr space. A color is assigned to each point in the YCbCr space.

Fig. 5 shows the results to recognize the color of objects on the field. Fig. 5(a) is the image used to construct the reference table. Fig. 5(b) by the previous method and Fig. 5(c) by the proposed method both show the sufficient color recognition. Fig. 5(d) shows the image under 800 lx and additional lighting of a incandescent lamp. Brightness itself was changed and color was changed because of the lamp with red-shifted spectrum. In this condition, the previous method failed to detect the landmarks (Fig. 5(e)) and on the contrary, the proposed method succeeded in precise color recognition (Fig. 5(f)) . Fig. 5(g) shows another example with the same lighting condition as Fig. 5(d). In this case, the previous method failed again (Fig. 5(h)). The proposed method produces much better results (Fig. 5(i)), but there exist some recognition failures for orange and yellow objects. This is because the cluster for orange was moved to the yellow pixels and consequently a mixtured wrong cluster of the table was produced at the update.

5.2 Ball Recognition and Measurent of Distance

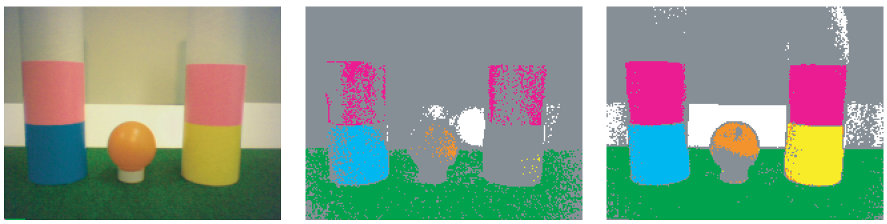
We conducted another experiment of recognizing the ball and measuring distance to it using the produced color table by the proposed color recognition methods. With its head shaking, the robot tried to recognize the ball and measure its distance. The ball was set at 300, 500, 1000 and 1500 mm from the robot. Twenty trials were performed for each distance. The distance to the ball was measured by two methods: using the number of pixels (when the ball is far) and using the geometrical configuration between the robot and the ball (when the ball is near). In both methods, the more precise the color recognition is, the more accurate the distance measurement becomes.

The illumination condition was 1200 or 800 lx by the fluorecent lights with or without a 100W blue incandescent lamp, i.e. four conditions. Table 1 and 2 show the number of successful experiments and results of distance measurement respectively.

From Table 1, we can observe the following. The previous method only succeeded when illumination was 1200 lx and every trial failed at 800 lx. It is because the pixel values of the ball went out of the range assigned in the reference table. On the contrary, the proposed method almost succeeded in every condition regardless of illumination. There are a few failures, in which an object other than a ball was recognized wrongly. This is because the cluster of the table invaded other color region at the update.

As for the distance measurement in Table 2, the proposed method produced more precise results in every condition. In the previous method, the number of recognized pixels decreases and thus the distance errors increase. The proposed method can recognize the pixels robustly, and consequently distance measurement becomes precise.

(a) Input Image (b) Previous method (c) Proposed method



(d) Input Image (e) Previous method (f) Proposed method

(g) Input Image (h) Previous method (i) Proposed method

Fig. 5. Input image and color recognized image by previous and proposed method

Table 1. Ball recognition (number for 20 trials)

Light	Method	1500	1000	500	300
		Recognition	Recognition	Recognition	Recognition
1200 lx	Previous method	20	20	20	20
	Proposed method	20	20	20	20
1200 lx + blue light	Previous method	20	20	20	20
	Proposed method	20	19	18	19
800 lx	Previous method	0	0	0	0
	Proposed method	19	20	18	19
800 lx + blue light	Previous method	0	0	0	0
	Proposed method	20	18	19	20

Table 2. Measurement of ball distance (unit: mm)

Light	Method	1500		300	
		Average distance	Standard deviation	Average distance	Standard deviation
1200 lx	Previous method	1873.9	57.5	366.7	13.8
	Proposed method	1526.4	38.4	310.8	8.7
1200 lx + blue light	Previous method	1920.9	35.4	385.9	5.5
	Proposed method	1535.6	23.3	325.8	6.4
800 lx	Previous method	×	×	×	×
	Proposed method	1752.5	45.6	316.4	4.7
800 lx blue light	Previous method	×	×	×	×
	Proposed method	1641.1	27.3	364.0	7.5

6 Conclusion

In this study, we have proposed a color recognition method which is robust to illumination change. A color space of Cb/Y and Cr/Y was introduced where Cb and Cr are color difference and Y is intensity of YCbCr color space. The color space is not affected by the brightness change. And a method to update clusters of color table was proposed. This method can cope with the change of the color of illumination. Experiments showed that the proposed method can recognize color more robustly for illumination change.

One problem is that the shift of the cluster of the table is sometimes not precise and it causes the failure of color recognition. Future work is to cope with this problem. And illumination model should be considered which includes mirror reflectance.

References

1. G. D. Finlayson, B. V. Funt. Color constancy under varying illumination. Proc. of IEEE Int. Conf. on Computer Visoin, pp.720 -725, 1995.
2. M. Sridharan and P. Stone: Toward Illumination Invariance in the Legged League. Proc. of RoboCup2004 Symposium, (CD-ROM), 2004.
3. M. Jüngel, J. Hoffmann, M. Lotzsch. A Real-Time Auto-Adjusting Vision System for Robotic Soccer. Proc. of RoboCup2003 Symposium, pp.214-225, 2003.
4. G. Mayer, H. Utz, and G. Kraetzchmar. Towards Autonomous Vision Self-Calibration for Soccer Robot. IEEE/RSJ Int. Conf. on Intelligent Robots and Systems (IROS)2002, pp.214-219, 2002.
5. R. Hanek, T. Schmitt, S. Buck and M. Beetz. Fast Image-based Object Localization in Natural Scenes. IEEE/RSJ Int. Conf. on Intelligent Robots and Systems(IROS)2002, pp.116-122, 2002.
6. I. Dahm, S. Deutsch, M. Hebbel, and A. Osterhues. Knowledge-based Autonomous Dynamic Colour Calibration. Proc. of RoboCup2003 Symposium, pp.1-12, 2003.
7. O. Faugeras, Three-Dimensional Computer Vision, MIT Press, 1993.
8. http://www.mvtec.com/