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Robust color tracking based on Mean-Shift under illuminance change

Koichi Hidaka[1]

[1]Department of Electrical and Electronics Engineering, Tokyo Denki University, Tokyo, Japan
(Tel: +81-3-5280-3316; E-mail: hidaka@eee.dendai.ac.jp)

Abstract: In this paper, we propose a color tracking method mean-shift based on the robust color system. Our proposed color system is simple calculation, and then proposed system can calculate faster than conventional normalized vector distance (NVD). We show validity of proposed method by experimental result that our method enables real-time color object tracking of illuminance changing conditions.

Keywords: Robust color system, Mean-Shift, Illumination change, blob tracking.

1. INTRODUCTION

Many techniques for tracking 2D blob through an image are proposed in computer vision, such as a tracking of persons[1], an automatic measurement of a traffic density[2], or robot position tracking[3]. These algorithms use camera as a device and the algorithms have to process an image on real time. For this reason, process speed is important. Mean-shift tracking method is efficient and nonparametric method for moving object tracking[3, 5, 7]. Mean-shift algorithm can track not only a rigid object but a non-rigid object and the algorithm has a low calculation cost and offers high speed execution. Then Mean-shift method is useful for the real-time tracking of moving object. Mean-shift algorithm based on conventional color system such as RGB, YUV or HSV, however, cannot perform the effective tracking when lighting environment changes. The paper[3] proposes an approach for color tracking under illuminance change. The approach uses some color-illuminance models and includes these models in mean-shift vector. However this method needs to know the illuminance intensity precisely.

This paper presents a color tracking method using mean-shift based on the robust color system. Our proposed color system is simple calculation, and then proposed system can calculate faster than conventional normalized vector distance (NVD). We show by experimental result that our method enables real-time color object tracking of illuminance changing conditions.

2. MEAN-SHIFT ALGORITHM USING ROBUST COLOR SYSTEM

2.1 Robust color system

CCD camera gives a color data of red, green and blue (RGB) to $N \times M$ image and these data are given by 8 bit. A pixel data on image plane (u, v) can shown as the color vector $\boldsymbol{I}(u, v)$ in figure 1 given by

$$\boldsymbol{I}(u, v) = [I_R(u, v), I_G(u, v), I_B(u, v)]^T \tag{1}$$

where $I_R(u, v), I_G(u, v), I_B(u, v)$ are red, green and blue data respectively and these vectors are given for the integer of 0 to 255. RGB can regard as vector with 3 elements and the length of vector and direction cosines are considered as brightness and hues, respectively. Since brightness is affected by illumination change, the color system such as hue in HSV is strong under illumination change. For this reason, the 2-norm of vector can be regarded as illumination and a conventional robust color system $\boldsymbol{I_r} = [I_{rR}, I_{rG}, I_{rB}]^T$ based on this idea is proposed as follows

$$I_{rR} = \frac{I_R}{||\boldsymbol{I}||},\ I_{rG} = \frac{I_G}{||\boldsymbol{I}||},\ I_{rB} = \frac{I_B}{||\boldsymbol{I}||} \tag{2}$$

where $|| \cdot ||$ shows 2-nolm and this color system is called as normalized vector distance (NVD)[7]. NVD is effective for color blob for varying lighting conditions. However, it is difficult for NVD to calculate color data on real-time such as 33[ms]. Then we propose a new color system based on Hue such as I_B/I_R and I_R/I_G shown in figure 1. We investigated all kind of ratio of R, G and B to decide an optimal combinations defined by $I_{r1} = I_B/I_R$ and $I_{r2} = I_R/I_G$. This color system can calculate faster because of computation of ratio of image data of pixel and proposed color system is calculable in about $1/3$ compared with NVD. We apply this color system to mean-shift and we verify that this color system is effective for color blob tracking for varying illuminance change condition.

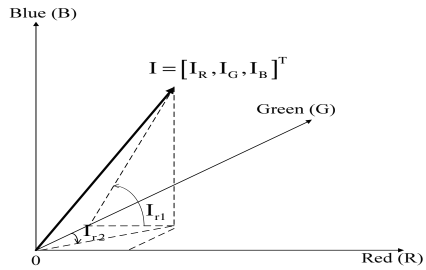

Fig. 1 Color space with red(R), Green(G) and Blue(B)

2.2 Mean shift algorithm

A tracking target model has to be expressed as a histogram and this target is given by an ellipsoidal region in the image. The reason why ellipsoidal region uses is that the tracking direction should not be continuous[5]. To emphasize the center of target and eliminate the influence of different target, a kernel function is made use of and normalized by a unit circle. Let $\{\boldsymbol{x}_i\}(i = 1, 2, \cdots, n_h)$ be the normalized pixel locations in the region of target

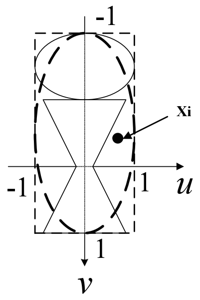

Fig. 2 Normalized pixel locations in the region of target image

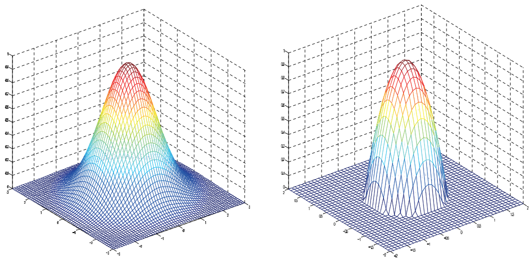

Fig. 3 Multivariate normal function(left) and epanechnikov function (right)

image shown in figure 2, where n_h is a size of target image. A number of $u - bin$ histogram $p_u(\boldsymbol{y})$ computed by the kernel $K(\cdot)$ is given by

$$p_u(\boldsymbol{y}) = C_h \sum_{i=1}^{n_n} K\left(||\frac{\boldsymbol{y} - \boldsymbol{x}_i}{h}||^2\right) \delta[b(\boldsymbol{x}_i) - u]$$
$$C_h = \left(\sum_{i=1}^{n_h}\left(||\frac{\boldsymbol{y} - \boldsymbol{x}_i}{h}||^2\right)\right)^{-1} \quad (3)$$

where $\boldsymbol{y} = [u_y, v_y]^T$ is a center of search point in image and u is a bin number given by $u = 1, 2, \cdots, 255$. C_h is the normalization constant and the function $b(\boldsymbol{x}_i)$ is defined as

$$b(x_i) = \begin{cases} u & (I[x_i] = u) \\ 0 & (I[x_i] \neq u) \end{cases} \quad (4)$$

$K(\cdot)$ is computed in the Epanechnikov function or multivariate normal function in figure 3 are usually used as kernel given by

$$K(||\boldsymbol{x}||^2) = exp\left(-\frac{||\boldsymbol{x}||^2}{2}\right) \quad (5)$$
$$K\left(||\boldsymbol{x}||^2\right) = \begin{cases} 1 - ||x||^2, ||x|| \leq 1 \\ 0 \qquad , otherwise \end{cases} \quad (6)$$

where Eq. 5 and Eq. 6 are multivariate normal function and Epanechnikov function.

This method moves to the maximum gradient density of matching index[5]. The Bhattacharyya coefficient is usually used as the matching index in this algorithm[5]. On the other hand, the other function is recently used as matching index[6]. To find the location corresponding to the target in the current frame, we have to move the center of search point $\boldsymbol{y}$ by using a matching index. The most maximizing distance is obtained by using the Bhattacharyya coefficient is defined as

$$\rho(\boldsymbol{p}(\boldsymbol{y}), \boldsymbol{q}) = \sum_{u=1}^{m} \sqrt{p_u(\boldsymbol{y}) q_u} \quad (7)$$

$\boldsymbol{p}(\boldsymbol{y})$ is a target tracking candidate at location $\boldsymbol{y}$ on image plane and $\boldsymbol{q}$ is a tracking template model. m is bin of color. $\boldsymbol{p}(\boldsymbol{y})$ and $\boldsymbol{q}$ are $m - bin$ histograms, so that $p_u(\boldsymbol{y})$ and q_u have the following features[5];

$$\sum_{u=1}^{m} q_u = 1, \sum_{u=1}^{m} p_u(\boldsymbol{y}) = 1.$$

Using Taylor expansion around the point $\boldsymbol{y}$, the Bhattacharyya coefficients (7) is approximated as

$$\begin{aligned} \rho(\boldsymbol{p}(\boldsymbol{y}), \boldsymbol{q}) &= \sum_{u=1} \sqrt{p_u(\boldsymbol{y})}\sqrt{q_u} \\ &\approx \sqrt{q_u}\left(\sqrt{p_u(\boldsymbol{y}_0)} + \frac{1}{2} p_u(\boldsymbol{y}_0)^{-1/2}(p_u(\boldsymbol{y} - p_u(\boldsymbol{y}_0)\right) \\ &= \sqrt{q_u}\left(\sqrt{p_u(\boldsymbol{y}_0)} + \frac{1}{2} p_u(\boldsymbol{y}) \frac{1}{\sqrt{p_u(\boldsymbol{y}_0)}} - \frac{1}{2}\sqrt{p_u(\boldsymbol{y}_0)}\right) \\ &= \frac{1}{2}\sum_u \sqrt{q_u}\sqrt{p_u(\boldsymbol{y}_0)} + \frac{1}{2}\sum_u p_u(\boldsymbol{y}) \frac{\sqrt{q_u}}{\sqrt{p_u(\boldsymbol{y}_0)}} \end{aligned} \quad (8)$$

where $\boldsymbol{y}_0$ is the center point in the current frame. Thus, the second term in Eq. 8 has to be maximized to find the next center point. Notice that $p_u(\boldsymbol{y})$ is given by Eq.(3). The second term in Eq. (8) can express as

$$\frac{C_h}{2}\sum_{u=1}^{m} \omega_i K\left(||\frac{\boldsymbol{y} - \boldsymbol{x}_i}{2}||^2\right) \quad (9)$$

where

$$\omega_i = \sum_{i=1}^{m} \sqrt{\frac{q_u}{p_u(\boldsymbol{y}_0)}} \delta(b(\boldsymbol{x}_i) - u)$$

We introduce a target's motion vector from $\boldsymbol{y}$ to a new location $\boldsymbol{y}_1 = \boldsymbol{y} + \Delta\boldsymbol{y}$ based on Eq.(9)[4, 5]. The function $f_k(\boldsymbol{y})$ is defined as

$$f_k(\boldsymbol{y}) = \sum_{u=1}^{m} \omega_i K\left(||\frac{\boldsymbol{y} - \boldsymbol{x}_i}{2}||^2\right). \quad (10)$$

By calculating the gradient of the function, we have a

$$
\begin{aligned}
\nabla f_k(\boldsymbol{y}) &= -2\sum_{x} K'\left(\|\frac{\boldsymbol{y}-\boldsymbol{x}_i}{2}\|^2\right)(\boldsymbol{y}-\boldsymbol{x})\,\omega_i \\
&= -2\sum_{x}\left(\omega_i K'\left(\|\frac{\boldsymbol{y}-\boldsymbol{x}_i}{2}\|^2\right)\right) \\
&\quad \cdot \left(\frac{\sum_x \boldsymbol{x}\omega_i K'\left(\|\frac{\boldsymbol{y}-\boldsymbol{x}_i}{2}\|^2\right)}{\sum_x \omega_i K'\left(\|\frac{\boldsymbol{y}-\boldsymbol{x}_i}{2}\|^2\right)} - \boldsymbol{y}\right)
\end{aligned}
$$

Thus, new location $\boldsymbol{y}_1$ is satisfied as $\nabla f_k(\boldsymbol{y}) = 0$ and we can give the new point as

$$
\boldsymbol{y} = \frac{\sum_x \boldsymbol{x}\omega_i K'\left(\|\frac{\boldsymbol{y}-\boldsymbol{x}_i}{2}\|^2\right)}{\sum_x \omega_i K'\left(\|\frac{\boldsymbol{y}-\boldsymbol{x}_i}{2}\|^2\right)}.
$$

This algorithm is based on the color data so that object tracking in illuminance change is difficult. Then, we apply this algorithm to the robust color system in order to decrease illuminance change.

3. TRACKING OBJECT BASED ON ROBUST MEAN-SHIFT ALGORITHM IN ILLUMINANCE CHANGE

We present a result of real-time object tracking in illuminance change using the mean shift algorithm based on the proposed color system. In the experiment, color markers of targets are red, green and blue. In this experiment, the target is moved by hand. Therefore, time to go through each target point is not same. Figure4 shows the experimental field and values of illuminance on the trajectory. The CCD camera mounted at a height of 155cm and the field domain is 170×130cm. The floor was covered with black paper in order to investigate the surface influence of target. The target starts lower right, and advances to the goal point on the left shown in figure4. Each

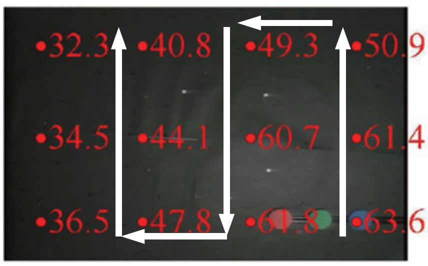

Fig. 4 (1):values of illuminance;(2):tracking path

Table 1 illuminance values on each point

	front	rear		front	rear
Point 1	49.3	63.6	Point 6	47.8	61.8
Point 2	60.7	61.4	Point 7	36.5	40.8
Point 3	61.8	50.9	Point 8	34.5	44.1
Point 4	40.8	49.3	Point 9	32.3	47.8
Point 5	44.1	60.7			

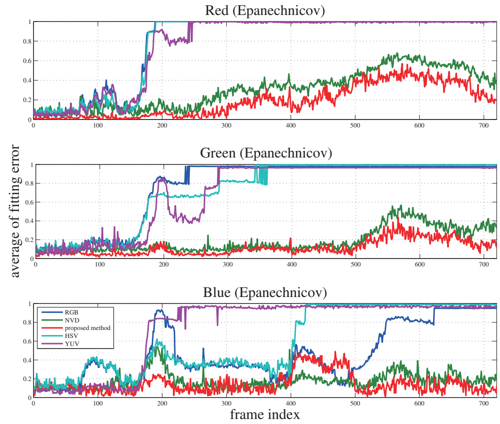

Fig. 5 average of fitting error based on Epanechikov function

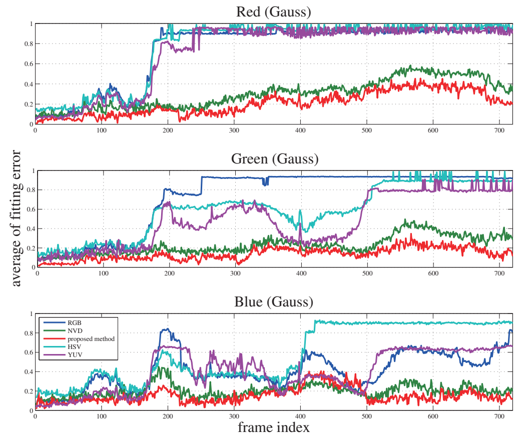

Fig. 6 average of fitting error based on Gauss function

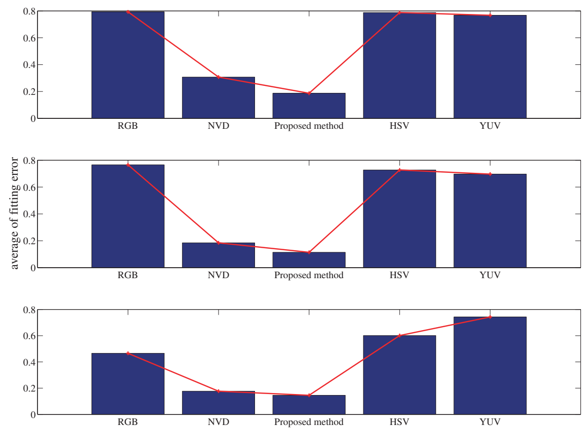

Fig. 7 average of fitting error

illuminance is not same on this field. Table1 shows values of illuminance on this filed. The values range from 32.3lx to 63.6lx. Since experimental field is covered with black sheet, black sheet decrease reflection of floor and illuminance change only affects the surface of target. we compare the proposed method with the other color systems such as RGB, YUV, HSV and NVD, mean shift using these color systems was demonstrated. Tracking path is given in figure. 4. The image size is 720×480 pixel and we used kernel functions as the Gaussian and Epanechnikov function given by Eq.(5) and Eq.(6). We estimated the fitting error by the distance between template and target as $\sqrt{1-\rho\left(\boldsymbol{p}(\boldsymbol{y}),\boldsymbol{q}\right)}$[3]. Figure.5 and figure.6 show the tracking performance. The kernel of figure.5 and figure.6 use Epanechikov and Gauss function. In these results, we consider tracking success when the Battacharrya coefficient is more than 0.5. Figure.5, figure.6 and figure.7 show that mean shift method based on RGB, YUV and HSV. RGB, YUV and HSV were not able to track after the point where illumination changed from 49 lx to 60 lx. On the other hand, the result of mean shift based on proposed method could track and attained good performance in this environment. Figure.6 shows that the tracking performance of proposed method and the method based on NVD have the same average of fitting error. Since calculation speed was able to decrease to $1/3$ compared with NVD and the color objects could track under the loose lighting environment change, it has checked that the proposed method is an effective technique.

4. CONCLUSION

In this paper, we have proposed a color tracking method using robust color system. The color system can calculate in real-time and the system can reduce the change of illumination and we showed the effectiveness of our proposed method by experiment result. Our future work is examination in rapid lighting change environment.

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