Object tracking with non-stationary cameras finds its applications in more and more areas, nowadays. One of the greatest limitations of tracking with a non-stationary camera is that a background reference image cannot be modeled, and motion information become less reliable than in the stationary camera case. Due to the uncertainty of motion information, other alternative features than the motion such as color or texture become important in the non-stationary camera case[1,2,3]. Among the tracking algorithms that use the color feature, kernel-based tracking algorithms have gained much attention due to their computational feasibility and promising results with complex camera motions and non-rigid target motion[4,5,6]. However, in spite of the fast speed, the mean shift approach lacks in stability in certain situations. For example, the original mean shift algorithm happens to fail to track the object if the translation of the object is large, a case that appears in low-frame-rate video in which objects have fast motion, or by the large panning operation of the moving camera. Therefore, the stabilization of the mean shift has been the major subject in the research of kernel based tracking algorithms. Several researches try to stabilize the mean shift by altering the weighting value and/or the kernel function[7][8]. Other approaches put the mean shift algorithm in the Kalman filtering or particle filtering framework such that the tracking becomes stabilized by the prediction of the Kalman/Particle filter[9][10]. In this paper, we propose a stable color based tracking algorithm based on a new representation of the target location: the area weighted mean of the centroids corresponding to each color bin of the target and background. The tracking based on this representation contains spatial information on the distribution of the colors, is rather insensitive to the loss of pixels and change in the number of pixels, and takes the colors into account according to the area they cover in the initial target region and background. Due to these properties, it possible to track the target in difficult conditions such as low-frame-rate environment, severe partial occlusion, similar color background environment and partial color change environment. Furthermore, the target localization can be achieved in a one step computation, which makes the algorithm fast. In next section, we describe our algorithm, then the next section we compare the stableness of the proposed tracking scheme with the conventional mean shift algorithm experimentally.

2. The Proposed Algorithm

The proposed area weighted centroids shifting algorithm takes the colors into account according to the area they cover in the initial target region and the background. Because the proposed algorithm weights according to the each color bin’s area, the tracking algorithm always reflects the major colors of the target more than the minor color. It contains more spatial information about the distribution of the colors in the target than the mean shift algorithm. The spatiality is provided not by a kernel but by an area weighted least squares approximation of the centroids corresponding to the color bins of the target and the background. This spatiality imposes a strong mutual constraint of the color bins on each other such that the drift due to the change in a certain color is alleviated by the mutual constraint. Due to the strong constraint, the target localization can be achieved by a direct one step computation even if the distance of the target in the previous and the current frame is large. The one step computation makes the tracking fast. Even if there is a background object which has similar colors with target’s, the proposed algorithm tracks the target stable because the weight of the color bins lowered in that case. Furthermore, since the computation of the centroids is not so sensitive to the number of pixels, the algorithms becomes stable against loss of pixels or change in the number of pixels in the target, which allows severe partial occlusion and partial illumination change.

The proposed area weighted centroid shifting algorithm derives from the following distance function:
where $\alpha_i$ is the weight to be explained later, $k_n^0$ is the main centroid of target to track, and $k_n^i$ is the sub centroid of the color bin $i$, which is calculated as

$$k_n^i = \sum_{p \in R} \frac{p \delta[f(p) - i]}{\sum_{p \in R} \delta[f(p) - i]}$$

The problem of finding the next main centroid has now become a weighted least square problem. The least square solution, i.e., the main centroid vector $k_n^0$ that minimizes (1) is the weighted mean of sub centroids $k_n^i$, that is,

$$k_n^0 = \sum_{i=1}^m \frac{\alpha_i k_n^i}{\sum_{i=1}^m \alpha_i}$$

We use the weight of (1) and (3) in the form of

$$\alpha_i = T\left(\frac{b_i}{t_i}\right) \cdot t_i$$

where $T(\cdot)$ is a background weight function, $t_i$ and $b_i$ is the area of color bin $i$ of the initial target and background respectively. The example of the weight function is

$$T\left(\frac{b}{t}\right) = \begin{cases} 1 & \text{if } \frac{b}{t} < \text{threshold} \\ 0 & \text{elsewhere} \end{cases}$$

which implies that the function returns “1” only if the area of color bin $i$ of the background is smaller than predefined threshold. Figure 1 describes the proposed algorithm graphically. The target to be tracked is a man who has 3 colors. Circled numbers stand for the centroids of each color bins and “something” stands for the position of main centroid which is the location vector of the target. It can be seen that, in spite of the varied positions of the target, the target location lies always almost at the center of the object. This is due to the fact that the target location is constrained to lie at the location that minimizes the sum of the weighted $L_2$ differences between the location of main centroid and the centroids $\{k_n^i; i = 1, \ldots, m\}$. The spatiality of the proposed distance function is provided with more inherent information about the distribution of the colors in the target than the mean shift algorithm. The drift created by a change in a certain color of the target is alleviated by the mutual constraints of the colors to each other and to the target location. Furthermore, the spatiality is not restricted inside a kernel region, and therefore the constraint takes effect even in the case that the displacement of the object is large. Without the background weight function $T(\cdot)$, which means

$$\alpha_i = t_i$$

tracking process affected by the background object which has the same color bin with target’s as shown in Figure 2 because of the occurrence of undesired centroid shift of the color bin. But owing to the background weight function, we can reduce the influence of background colors.

Now, in the next frame, the location of the target can be represented as

$$k_n^{i+1} = \sum_{i=1}^m \frac{\alpha_i k_n^{i+1}}{\sum_{i=1}^m \alpha_i}$$

where $k_n^{i+1}$ is the centroid of the pixels that belong to the color bin $u$ of the target in the next frame. The computation of $k_n^{i+1}$ is performed inside a sub-region which is centered at $k_n^0$ and is large enough to include the target in the next frame. Then, the shifting vector $\mathbf{k}_n^{i+1 \text{shift}}$ that shifts the location of the target in the current frame to the location in the next frame can be directly computed by taking the difference of and , that is,
The shifting vector is computed directly in one step and therefore the proposed algorithm does not require an iterative procedure as the original mean shift tracking. The one step computation makes the algorithm simple and fast.

3. Experimental Results

The video sequence in Figure 3 has been obtained by a pan/tilt camera with manual pan/tilt operation. The large panning operation resulted in a low-frame-rate video sequence, such that the displacement of the target is rather large. This large displacement results in the tracking failure with the mean shift tracker as can be observed in the left column of Figure 3. The use of the kernel increases the instability in this case, since the background colors are emphasized by the kernel as they appear near the center of the previous target region. However, the target can be tracked stably with our proposed tracking algorithm employing background weight function as can be seen in the right column of Figure 3.

Figure 4 shows the tracking result when partial occlusion is present. The left column of Fig. 4 shows that the mean shift algorithm is sensitive to the loss in pixels due to the occlusion. The change in the weighting results in a drift in the mean shift and the target becomes lost. The right column of Fig. 4 shows the tracking result with the proposed algorithm. The stability against the loss in the number of pixels results in a stable tracking result. The proposed algorithm can track the target well, even in presence of severe occlusion as can be observed in bottom row of Fig. 4. In this case, the pixels in the target that are not occluded by the tree, which are small in number, lead the tracking. This is possible as the proposed algorithm takes the average value of the pixel locations, and not the number of pixels into account.
4. Conclusion

In this paper, we proposed a new tracking algorithm, which has the properties of being insensitive to the loss of pixels, containing good spatiality, and taking the colors into account according to the area they cover in the initial target region and the background. The tracking algorithm based on this representation is fast, and stable enough to track under difficult situations such as low-frame-rate environment, severe partial occlusion and partial color change environment. The stability of the proposed tracking has been shown by experimental results. The result of the proposed algorithm outperforms the mean shift algorithm.

Acknowledgment

This research was supported by the MIC(Ministry of Information and Communication), Korea, under the ITRC(Information Technology Research Center) support program supervised by the ITA(Institute for Information Technology Advancement) (ITA-2008-(C1090-0801-0012))

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