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# Comparative Performance Evaluation of Various Color-Based Object Tracking Methods

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**Abstract** —*Extensive research in object detection and tracking has produced many techniques for detecting and tracking objects in videos. The most widely researched techniques include color-intensity based, particle filter based and optical flow based trackers. Each technique has its own merits and limitations. This paper presents a comparative performance evaluation of these leading object detection and tracking techniques. After a brief overview of various techniques, viz. particle filter, color-intensity based and color optical flow trackers, that directly or indirectly uses color for the purpose of object detection and tracking, their performance on a test video is reported in this paper.*

***Keywords*** — *Object detection, object tracking, optical flow, particle filter, color-based tracking*

## I. INTRODUCTION

Object detection and tracking is one of the active research areas of computer vision. It has many practical applications, such as analysis of sport videos to detect faulty motions of a sportsman, tracing the trajectory of an object of interest, human computer interaction, target localization, event analysis, etc. Object detection refers to finding the object of interest in a scene while object tracking refers to locating the object of interest in successive video frames for generating the trajectory, for example tracking the trajectory of a moving car to find lane violation.

Object tracking is a challenging problem in a natural scene due to abrupt changes in object motion directions, changes in appearance of the object in different frames, object occlusion, illumination changes, non-rigid transformation of objects, noises in images, and computational complexity to meet real time processing requirements. A robust object tracker should be able to track single or multiple objects moving in a dynamic background. Typically, an object tracker consists of three modules [1]: Object Detection, Object Modeling and Object Tracking. During the last two decades, various object tracking methods have been emerged focusing on designing a robust tracker. A categorization of various tracking approaches is presented in [1].

This paper investigates comparative performance of some of the leading object tracking methods, viz. color-based method, optical flow method and Particle filter method, to track a red color object. These three methods are briefly discussed in the following sections for tracking primary color objects; their comparative evaluation in terms of performance is also presented. The results are reported for a test video captured by the author in common household lighting conditions.

The remaining part of the paper is organized as follows: Section 2 describes the basic work flow of a typical color-based object detection and tracking system. Section 3 presents a brief description of color-intensity based object detection and tracking system developed by the author. Section 4 presents a color-based optical flow method, which is modified by the author to handle a dynamic background. Section 5 discusses the standard color-based particle filter method, which is commonly used by the researchers. In section 6, the results of the methods developed/modified by the author are evaluated and compared with the results obtained by the standard particle filter. Finally, conclusions are drawn and the direction for the future research is proposed.

## II. COLOR-BASED OBJECT DETECTION AND TACKING METHODS

Color is one of the most important features of an object that is used extensively in literature to detect and track objects. The basic work flow in typical color-based object detection and tracking system is given in figure 1. Recent advances using color as a feature often use color histograms to model the object. Besides having low computational cost, color histogram distribution is robust against non-rigidity, scale and rotation transformation of objects.

 

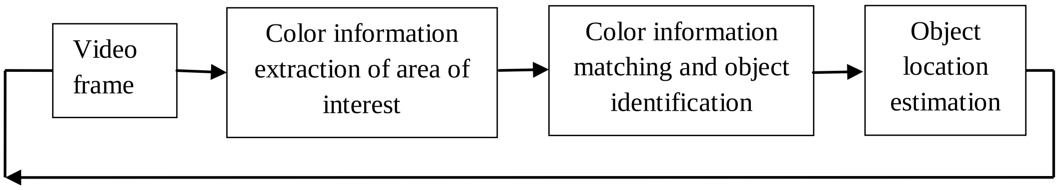


***Figure 1: Color-based object tracking work flow [2]***

This paper is primarily focused on the performance evaluation of three color-based object detection techniques: color-intensity based method [2], optical flow method [3] and particle filter [4,5]. Before comparing the performance of these methods to track a red color object, a brief description of each method is presented in the subsequent sections for easy comprehension. More detailed description of these methods along with their strengths and limitations can be found in [1,6].

## III. COLOR-INTENSITY BASED METHOD

A very efficient formula for converting a RGB video frame to an intensity video frame that highlights a desired primary color in the image is reported in [2]. The author found that for detecting and tracking a red color object in a video, using the RGB color representation scheme, the ratios of the red value with respect to the green and blue values of a pixel are more important than the absolute red value of the pixel. The formula to highlight red color shades and suppressing other colors is given by equation 1:

$$I = \frac{R * R}{G * B} \tag{1}$$

where *R*, *G*, and *B* are the red, green and blue values of a pixel, and *I* is the calculated intensity of the pixel. The formula is applied to all the pixels of the image to obtain the intensity image. The intensity image is further processed by a predefined threshold value to further enhance red color pixels. Similarly, to highlight green and blue color shades, equations 2 and equation 3 are used, respectively on the entire image to obtain the intensity image.

$$I = \frac{G * G}{R * B} \tag{2}$$

$$I = \frac{B * B}{G * R} \tag{3}$$

To detect a desired object of any primary color shade, firstly, the thresolded color-intensity image is obtained using the respective equation mentioned above. Noises are then removed by applying a median filter to the thresolded color-intensity image. Finally, centroid is calculated as the mean of the positions of the bright pixels. The centroid is computed in each frame, using the above process, to generate the trajectory. The drawback of the intensity based method is that the method is able to segregate objects of primary color shades and the formula is ineffective for combined colors.

## IV. OPTICAL FLOW BASED TRACKING METHOD

Optical flow is a technique to find moving objects from two consequent video frames by observing the motion of intensities of pixels, under the assumption that the intensities of the pixels of the object of interest are constant and are not changing from frame to frame. Researchers believe that this is the primary mechanism used in animals to track objects along with some mechanism (still not known) to adjust to illumination and appearance changes. Computationally, optical flow estimation yields a two-dimensional vector field, i.e., motion field, that represents velocities and directions of each pixel of an image sequence [7]. Discontinuities in the optical flow can help in segmenting images into regions that correspond to different objects. In a static camera video, the motion of the moving objects is represented by the relevant shift of the pixels in the consecutive frames, with assumptions that a pixel of certain intensity or colour in $t^{th}$ frame will not move too far in the $(t + 1)^{th}$ frame and that the colour or brightness of the pixel is constant in the two frames. This small motion of a particular pixel can be obtained using the optical flow method [7].

Mathematically, let I(x,y,t) is the centre pixel in a *n x n* neighbourhood and is displaced by δx and δy in time δt to I(x+ δx,y+ δy,t+ δt) such that δx, δy and δt are not very large values. Since, both pixels are the images of the same point, with the brightness constancy assumption, therefore equation 4 holds.

$$\mathrm{I(x, y, t) = I(x + \delta x, y + \delta y, t + \delta t)} \quad (4)$$

Using Taylor series for the right-hand side of equation 4

$$\mathrm{I(x + \delta x, y + \delta y, t + \delta t) = I(x, y, t)} + \frac{\partial I}{\partial x}\delta x + \frac{\partial I}{\partial y}\delta y + \frac{\partial I}{\partial t}\delta t + \mathrm{H.O.T} \quad (5)$$

From both equations 4 and 5, neglecting higher order terms and after modifications, equation 6 is obtained

$$I_x v_x + I_y v_y = -I_t \quad (6)$$

In vector representation

$$\nabla I \vec{v} = -I_t \quad (7)$$

Where $\nabla I$ is called the spatial intensity gradient and $\vec{v}$ is the optical flow (image velocity) at pixel (x,y) at time t. $I_t$ is the time derivative of the brightness intensity. Equation 7 is called 2D motion constraint equation and is the important equation for motion estimation. At present, there are several methods, such as Lucas-Kanade, Horn-Schunck, for optical flow estimation.

In this paper, instead of using the standard intensity image for optical flow calculation, the intensity images generated by the author's formula have been used. This is done to enable optical flow to handle a dynamic background and track an object of desired color. With this simple modification, it is found that optical flow is very efficient, and it accurately detects and track objects of a desired color.

## V. PARTICLE FILTER BASED TRACKING METHOD

Particle filter is a state estimation method for systems with non-linear process and measurement models corrupted with noise which may be non-Gaussian and multimodal [8]. A particle is a sample of possible states of objects. Each particle contains a state estimate $x_t$ and associated weight $w_t$ corresponding to sampling probability. These weights define the importance of a sample and its likelihood to be considered in future. The state vector of each particle is given by equation (8).

$$x_n = [x, y, \dot{x}, \dot{y}] \quad (8)$$

Particle filter algorithm is recursive in nature and consists of two stages: prediction and update.

**Prediction** - The prediction stage uses the system model to predict the state pdf forward from one measurement time to the next. The prediction step uses a predefined motion model for the next time step. After initialling the state vector of each particle with random values, a motion model, given in equation [9], is used to predict the state vector for the next time step.

$$x_t = A x_{t-1} + w_{t-1} \quad (9)$$

where A defines the state transition model, and $w_{t-1}$ defines the Gaussian random noise, $x_t$ is the predicted state at time t, $x_{t-1}$ is the previous state. For A, a first order dynamic model is used. Here, it is assumed that the object is moving with constant velocity $\dot{x}$ *and* $\dot{y}$.

**Updation**- In this step, the latest measurement data is used to modify the predicted pdf using an observation model. In a color-based particle filter method to detect and track a red color object, the commonly used observation model is used, as given in equation 10 and 11.

$$w_t = \frac{1}{\sqrt{2\pi}\sigma} . \exp\left(-\frac{d^2}{2\sigma^2}\right) \quad (10)$$

$$d = \sqrt{(r - 255)^2 + g^2 + b^2} \quad (11)$$

where r, g and b are the red, green and blue components of a pixel's color in the RGB color model. Equation 11 assigns a larger weight to a particle located at a pixel whose color is closer to the red color. Finally, the particles for the next step are selected using resampling with replacement to avoid degeneracy problem. Here, larger weight is given to particles which are closer to red color.

## VI. EXPERIMENTAL PERFORMANCE EVALUATION AND COMPARISON

For the performance evaluation and comparison of the above three methods, the methods are implemented in MATLAB 2017(Academic) running on an Intel(R) core(TM) i7-4790 CPU @ 3.6 GHz machine with 4 GB RAM and 64 bit Windows 8 operating system. Many test videos are captured in a standard household lighting condition. However, the results generated by the above three methods, that are included in this paper are based on a test video in which a red color plastic bat moves around a normal study chair with handles.

The results of the two modified methods are compared with the standard color-based particle filter method. Figure 2 shows some sample frames of the test video along with centroids of the tracked object calculated by the three methods. Figure 3 shows the 2D image plots of the entire tracked paths created by the tested methods.

Frame 10

Frame 50

Frame 100

Frame 125

Color-based tracker | Color-optical flow tracker | Particle filter tracker

***Figure 2: Sample output frames of the test video generated by various methods***

Figure 4 shows the 2D plot of the tracked path superimposed in a single plot. From figure 4, it can be clearly seen that the path generated by particle filter has lots of waviness as compared to color-intensity based and optical flow trackers. Further, the initial portion of the path generated by the particle filter method contains large error due the warming up period of the particle filter. This should be taken considered when using particle filter to track objects in real situation. The results of color-based tracker and optical flow tracker are quite close to each other. However the path generated by the optical flow method is smoother than the path generated by the color-based method. Figure 5 graphically shows the pair-wise error comparison of different methods. The error is calculated as the Euclidian distance (in pixel units) between the centroids computed by the different methods. The mean computation time, as reported by the run and time utility of MATLAB, of the different methods is tabulated in table 1. It can be seen from table 1 that particle filter is the fastest of the three compared methods.

a) Tacked path generated by color-based tracker

b) Tacked path generated by color-optical flow tracker

c) Tacked path generated by particle filter tracker

***Figure 3: Tracked paths generated by different methods***

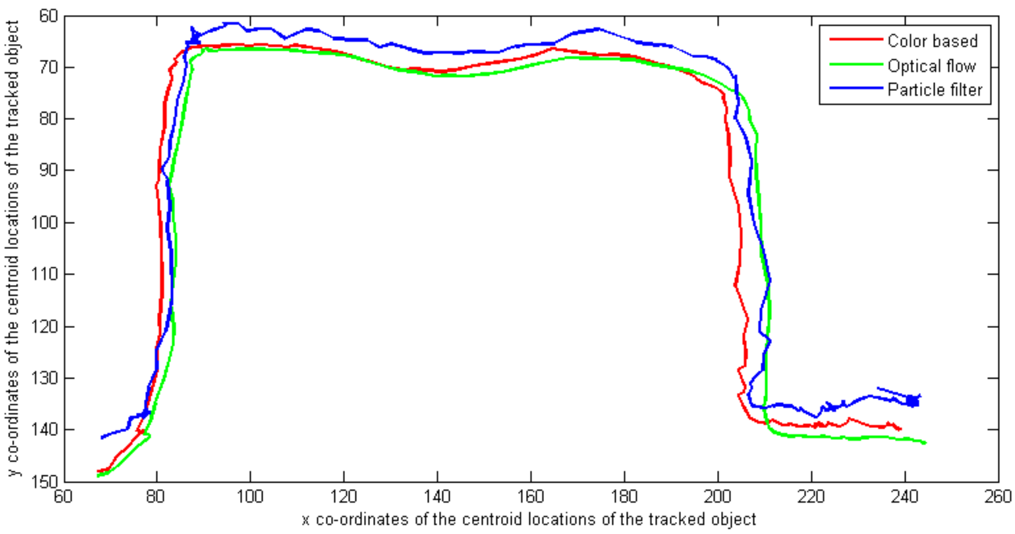


***Figure 4: xy plots of the locations of the centroid of the tracked object generated by different methods***

**Table 1: Mean computation time of the different methods to generate tracked path for the test video**

| Particle filter | Color-intensity based | Optical flow |
|---|---|---|
| 0.117 s | 0.451 s | 0.628 s |

## V CONCLUSIONS

There are many techniques that use color as a feature to detect and track moving objects in videos. The leading ones among them are particle filter, color-intensity based and optical flow trackers. This paper reports the comparative performance evaluation of these techniques on a test video captured by a video camera under a normal house-hold lighting condition. It is found that the particle filter is comparatively faster as compare to the color-based tracker and the optical flow tracker. However, the later two methods outperform the particle filter in terms of positional accuracy. Hence, further researches are required to improve the accuracy of the particle filter and computational speed of the other two methods.

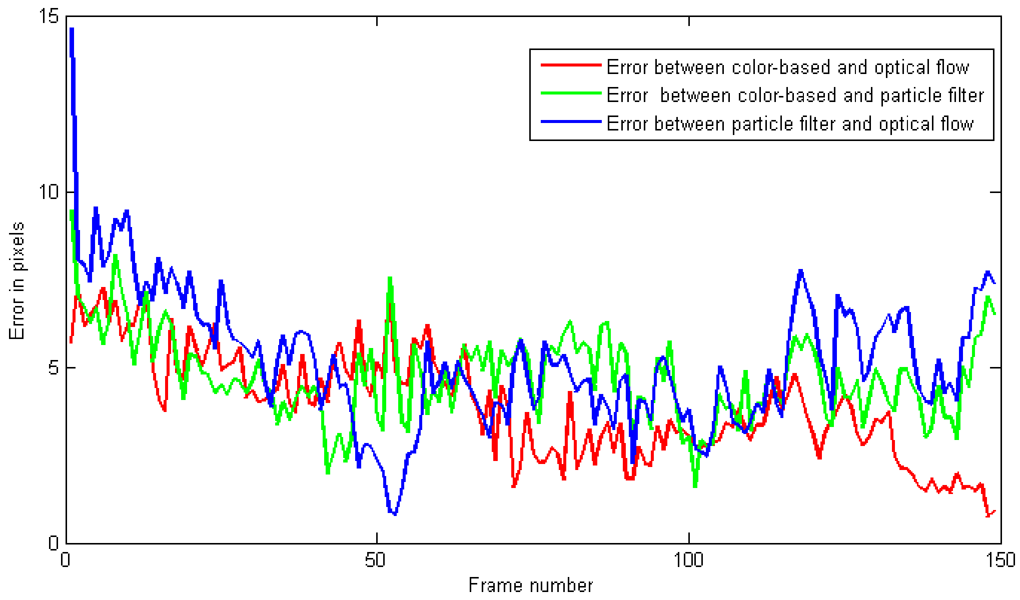


***Figure 5: Frame-wise relative errors of tracked locations generated by different methods***

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