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Vehicle Detection and Tracking by Localizing Rear Lamps and License Plate

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***Abstract*—**Automatic vehicle detection and tracking is an essential processing system for an intelligent transport applications. However, it is posed to great challenges such as landscape variations, vehicle speed, dimension, color, etc. This paper introduces a methodology to detect and track the rear view of vehicles from videos. The methodology adopts two different color space models to detect rear lamps and rear license plates, respectively. Kalman filter is used to estimate and track the moving object and further to aid in detecting and tracking the vehicles. The relationship between the locations of the rear lamps and license plate are used to construct the Markov model, which detects and tracks the vehicle based on the kalman filter output. The experimental investigation shows the methodology maintains minimum error on detecting and tracking the vehicles. The developed user interface is believed to be useful for applying the system comfortably.

Index Terms*—vehicle detection, kalman filter, Markov model, tracking, rear lamps*

I. Introduction

PREVENTING accidents and ensuring road safety are the primary concerns for any nation and hence numerous national as well as international projects have been unveiled in the past few years [5]. The projects include on-road vehicle detection that detects vehicle from the images acquired while in moving vehicles [10]. The vehicle detection process not only plays crucial role in road safety, but also in intelligent transport system applications such as self-guided vehicles, driver-assistance systems, and automatic parking systems [8].

Active sensors such as lasers were proven for prototype vehicles, but they are costly, highly interfering with other electronic devices and low resolution. Hence, passive sensors such as cameras are found to be promising in the later era. While using such sensors, it is highly significant to process visual information acquired from the camera [7]. Though the camera is powerful, poor visual information processing may lead to poor reliability on vehicle detection process [6]. Computer vision algorithms play crucial role under such circumstances.

The continuous changes in the landscape along the road sides, lighting changes due to day/night variations, climate variations, etc, different vehicle speeds, color, size and other vehicular parameters pose great challenges to the vehicle detection and tracking process [8] [11]. In addition with these challenges, rapid urbanization, traffic and direction of vehicle movement has increased the difficulties [1]. Hence, the automatic detection and tracking of vehicles is essential in the current situation [9].

This paper proposes vehicle detection and tracking method based on the relationship between the location of rear lamps and license plate. An initial prediction of moving object is carried out by kalman filter. However, the final vehicle detection and tracking is done by markov model based on the kalman filter results and the relationship between the rear lamps and license plate positions. The paper is further organized as follows. Section II provides the basic explanations about kalman filter and markov model. Section III details the proposed methodology with required illustrations. Section IV discusses the results and Section V concludes the paper.

II. Preliminaries

A. Kalman filter

Kalman filter is a linear quadratic estimator to estimate an unknown dependent variable based on previous observations under a noisy, imprecise and uncertain environment. The high level definition for the kalman filer says that it optimally estimates the state of the system using noisy and uncertain data through a recursive process [12]. The kalman filter is well known for its feasibility under real environment, precise results and simplicity. Kalman filter find numerous applications, especially in navigation and control of vehicles, aircrafts, spacecrafts, robots, etc [13].

The algorithm has two major steps, namely, prediction and updating. The prediction step predicts the variables of the current state along with the degree of uncertainty, while in the updating step, the predicted variables are updated using a weighted average measurements in which more weight is assigned, when the degree of uncertainty is less. The recursive nature of the algorithm allows it for real time processing, because it does not require any information, except previous and current state measurements [12].

In our work, we use the algorithm for motion estimation so that the moving object in the given video is estimated. The moving object can be a vehicle or non-vehicle. However, it localizes the moving object at every frame and also produces the trajectory of the object to further assist in detecting and tracking the vehicle.

B. Markov model

Markov model is stochastic model that predicts the future state based on the Markov property. According to the Markov property, the output of a system highly relies only on its

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previous state, and not on the other preceding states. The Markov model acquires the probable states of the given system, transitions paths between every state to the other state and rate/probability of the transitions. A typical Markov model has circles as states and the arrows/links between the circles refer to the transition between those states.

Our paper considers the states vehicle and non-vehicle so that it estimates the probability of transiting an object from being vehicle to non-vehicle and vice versa based on the characteristics of the objects. One of the characteristics is the kalman filter output, while the other characteristics are the localizing results of rear lamps and license plate.

III. Proposed Methodology

The proposed vehicle detection and tracking system is comprised of four stages, namely, vehicle rear lamp detection, rear license plate detection, estimating motion object and detecting vehicle. The architecture diagram of the proposed vehicle detection and tracking algorithm is illustrated in Figure 1.

According to Figure 1, the input video is subjected to image sequencing in which the video is defined as sequence of images in standard size. These image sequences are subjected to three stages, namely rear lamp detection, rear license plate detection and motion estimation using kalman filtering method. A markov model is constructed based on the information obtained from rear lamp detection and rear license plate detection. This markov model is subjected to detect and track the vehicle based on the motion estimation results.

A. *Rear lamps detection*

The rear lamp detection process gets image sequence and undergoes three basic operations such as color space conversion, post processing and detecting. The image sequences are acquired in RGB color space. However, rear lamps cannot be visualized or detected in this color space. Hence, the sequences are converted from RGB color space to a different color space in which the rear lamps can be detected precisely. We have adopted the color space conversion model proposed in [1], which are as follows.

$$I_{RC}^{i} = I_{R}^{i} - \max\left(I_{G}^{i}, I_{B}^{i}\right) - 2\left|I_{G}^{i} - I_{B}^{i}\right| : 0 \le i \le N-1 \qquad (1)$$

Where, I_{RC}^{i}, I_{R}^{i}, I_{G}^{i} and I_{B}^{i} refer to the i^{th} image in rear lamp color space, R band, G band and B band, respectively. $|\bullet|$ represents norm function and N refers to the total number of frames or images in the sequence.

In order to improve the precision of the rear lamp detection precision, a post processing step is included. In the post processing step, firstly the contrast of I_{RC}^{i} is improved followed by binarizing the contrast enhanced image. The binarized image is morphologically eroded and hence the rear lamps are obtained in the images as white pixels, whereas the remaining foreground and background objects appear as black pixels.

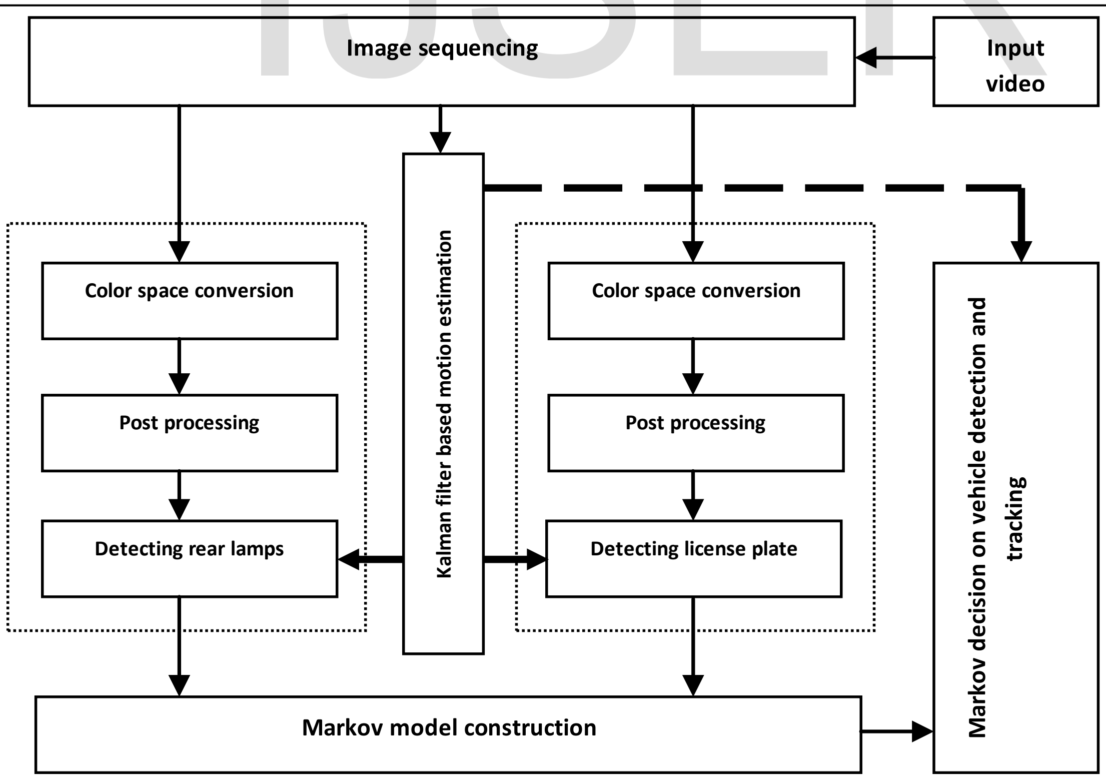

Fig. 1. Architecture diagram of the proposed methodology

B. Rear license plate detection

The processes included in detecting the rear license plate of the vehicle are similar to the rear lamp detection processes, except the color space conversion model. According to [1], the color space conversion model that supports rear license plate of the vehicle is given as follows

$$I_{LP}^{i} = I_{B}^{i} - \min(I_{R}^{i}, I_{G}^{i}) \qquad (2)$$

where, I_{LP}^{i} is the i^{th} image in license plate color space. Similar to rear lamp detection process, the images in license plate color space model are subjected to contrast enhancement, binarization and morphological erosion to detect the rear license plate of the vehicle.

C. Motion estimation using kalman filtering

Motion estimation is the process of determining motion vectors from a sequence of frames. Exploiting kalman filtering process for motion estimation has been reported in the literature since 1990s [2]. It has been referred as one of the promising techniques for effective motion estimation and hence numerous variants of this algorithm have also been reported [3] [4]. Hence, our paper exploits kalman filter to estimate the moving object in the given image sequence. The estimated moving object is used for detecting rear lamps, license plate and also for markov decision.

It is known that in the rear lamp and license plate detection processes, rear lamps and license plate are in white pixels and the other foreground and background objects are in black pixels, respectively. However, it shall not be precise enough to drop all such undesired objects. Based on the kalman filtering output, the misinterpreted rear lamps and license plate are dropped. Similarly, the kalman filtering output is used at the final decision making process also.

D. Markov model for detecting/tracking vehicle

The markov model for detecting/ tracking vehicle is constructed based on the relationship between the positions of the left and right rear lamps and the rear license plate. Once the probability of being the vehicle is ensured by the markov model, the final prediction improvement is taken place using the prediction results of kalman filter.

The markov model is constructed based on five interpreted conditions as follows

Condition (i): $l_x > L_x^{left}$ (3)

Condition (ii): $l_x < L_x^{right}$ (4)

Condition (iii): $L_x^{left} < L_x^{right}$ (5)

Condition (iv): $l_y < L_y^{left}$ (6)

Condition (v): $l_y < L_y^{right}$ (7)

Based on the aforesaid conditions, emission matrix and the decision model are constructed.

IV. Results and Discussion

A. Experimental Results

The proposed methodology is simulated in MATLAB and experimental investigation is carried out. For a given video, the rear lamps and license plate are detected followed by motion estimation using kalman filter. The image results obtained for the three processes are given in figures 2, 3 and 4, respectively.

There are multiple localizations of rear lamps and license plates. For instance, left top and right bottom images of figure 2 have more minor centorids. However, these imprecise centroids will be neglected, when the conditions given in Equations (3) – (7) are considered. Similar circumstances occur in figure 3 also. Figure 4 illustrates the prediction of moving object by kalman filter. These prediction results are highly useful for the markov model to detect and track the vehicles.

B. Error metric

The performance of the proposed methodology is investigated using error metrics. The error is determined as the absolute difference between the centroid of the actual vehicle and predicted vehicle. There are 56 frames in the subjected input video and hence we have determined 56 error metrics for all the frames followed by averaging them. Thus obtained mean error is around 11.40 (approx.). The box plot and instantaneous error are illustrated in figures 5 and 6, respectively.

The box plot in figure 5 shows that the median error metric remains in around 8 (approx.), whereas the minimum and maximum error reach to 0 (approx.) and 32 (approx.), respectively. Few outliers shall go beyond 100 (approx.). More detailed and instantaneous version of the metrics can be visualized through figure 6.

(a) (b) (c) (d) (e)

Fig. 2. Detection and tracking of rear lamps for an image sequence. Please note that the given sequence is intermediate samples and not temporally interlinked with each other.

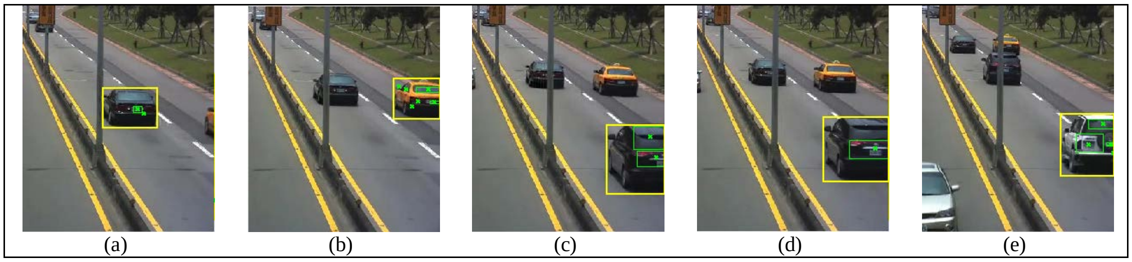

Fig. 3. Detection and tracking of license plate for an image sequence. Please note that the given sequence is intermediate samples and not temporally interlinked with each other.

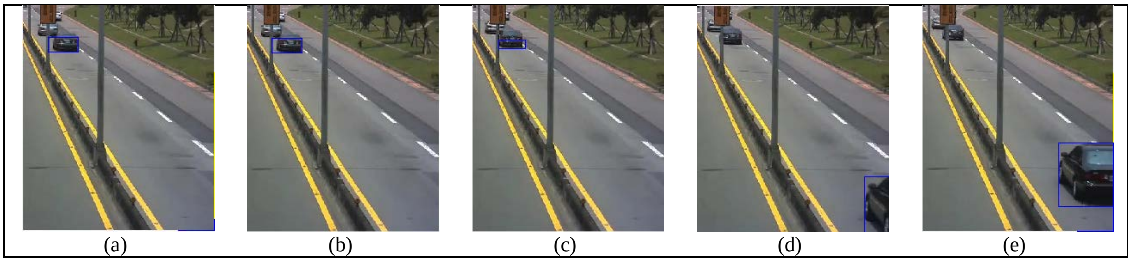

Fig. 4. Detection and tracking of vehicle by kalman filter for an image sequence. Please note that the given sequence is intermediate samples and not temporally interlinked with each other.

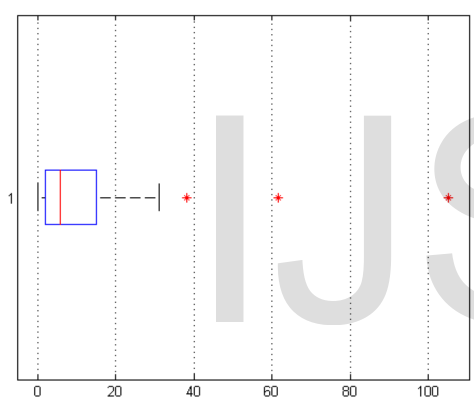

Fig. 5. Box plot to describe the statistical relationship of the error between the detected and the actual posture of the vehicle

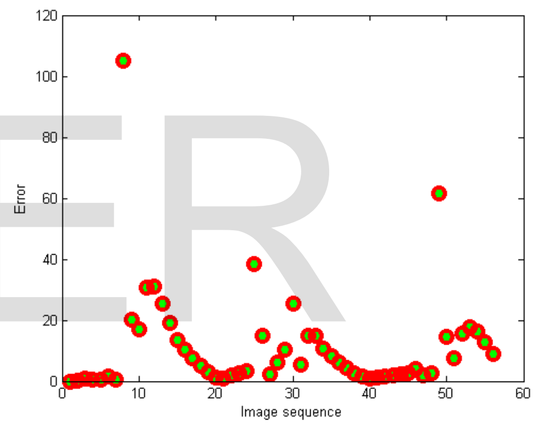

Fig. 6. Instantaneous error between the detected and the actual posture of the vehicle

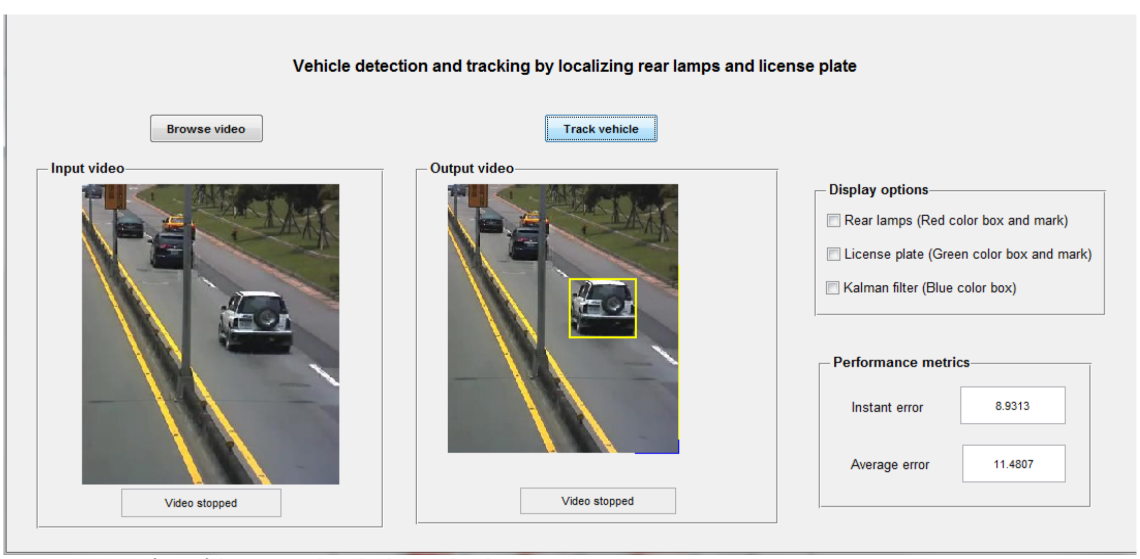

Fig. 7. User interface of the proposed methodology developed in MATLAB

C. User Interface

A user interface is developed in MATLAB for working on the methodology. The developed interface is illustrated in figure 7. The interface has a button, named as "Browse video" to browse and load input video, and an execution button, named "Track vehicle", to track vehicles in the loaded video.

The corresponding videos are played just below the buttons, whereas the status of the videos (whether it is being played or stopped) is displayed just below the video. The interface has three "Display options" to display the centroids of detected rear lamps and license plate as well as its approximated bounding region. Moreover, there is an option to display the kalman filter output also. The performance metrics are instantaneously updated in the "Instant error" box and the average of the instant errors are displayed in the "average error" box. The interface is developed for simple execution of the methodology. It shall be subjected to further enhancements so that the user can access the methodology intensely.

V. Conclusion

This paper has introduced a methodology to detect and track vehicles based on the location of rear lamps and license plate. Rear lamps and license plate of vehicles have been determined in a dedicated color space model to improve the precision. Kalman filter has been used to estimate the motion object as well as to ensure the performance of the rear lamp detection process and license plate detection process. The spatial relationship between the locations of the rear lamps and the license plate has been used to construct the markov model and hence the vehicle has been detected and tracked throughout the video. The experimental study on the methodology has revealed its reduced deviation between the actual vehicle and the tracked vehicle. The methodology shall be considered for further enhancement so that it can be applied in many real world applications, especially in intelligent transportation systems, surveillance, etc.

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