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Front Moving Vehicle Detection and Tracking with Kalman Filter

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Abstract—**Immature behavior, fatigue, and inattentional driving have been mainly identified as major issues in safety. Such human behaviors are considered to be the core problem for the occurrences of traffic accidents. As a result, Intelligent Transportation System including Safety Driver Assistance Systems plays an important role in traffic safety. This system becomes the focused research topics recently. This paper aims to make an investigation of front moving vehicles detection and tracking for the forward collision warning system. In the proposed system, there are two major parts, i.e. vehicle detection and vehicle tracking for position prediction. For the detection procedure, this paper makes use of computer vision techniques with shifting three frame difference method on video sequence and combines with edge detection. For object's boundary selection, this work applies the blob-detection to extract the center of mass and the bounding box features of the detected object. After having selected those features of the front vehicle the tracking process is carried on by utilizing Kalman filter algorithm in order to improve the accuracy of object detection and position prediction. Three videos obtained on the urban structured road in Thailand are tested. Experimental results show that the detection rate of front moving vehicle performs better when Kalman filter is applied for tracking.**

Keywords-front object detection; object tracking; Kalman filter algorithm

I. Introduction

Front vehicle detection and tracking for position prediction in video scene of high-way application are crucial tasks for Intelligent Traffic Safety System (ITSS). Such system is applicable in incorporating Electronic, Computer and Communication technologies into vehicles for traffic death reduction, assisting drivers, and enhancing passengers safety. Furthermore, not only collision avoidance system but also traffic monitoring system and others traffic surveillance systems require the detection technique.

Many researchers have proposed methods for front moving object detection. For example, Zhou and Hoang [1] proposed background subtraction technique for real time robust human detection and tracking system in video surveillance. In the experiment, they used videos with different environment as the inputs and the results were proved to be robust; however, this method seemed to work only with the stationary camera and not satisfied with non-stationary camera. Moreover, there were also false detection if the foreground was affected by the shadow. A cooperative work by Srilekha et.al [2] introduced a new technique for detecting, tracking, as well as counting the vehicles based on Kalman filtering approach. The proposed method utilized an updating state estimation of Kalman filter to update the background model over time. The results had better accuracy compared to background subtraction method. However, its major limitation was inability to manage dynamic background pixels and a non-stationary camera. Yadav et.al [3] presented a real-time vision based method for detecting vehicles in both rear and forward collision warning system. The proposed work consisted of two different modules. One was corresponded for vehicle in the forward path and the other for passing-by vehicle. For the localizing forward path vehicle, the authors utilized Profiling and Edge detection techniques while the passing-by vehicle detection they made use of temporal differencing method. The results had been demonstrated high performance of the system and low false positive rate for the in-path vehicle. However, it was degraded under rainy weather scenarios because of improper segmentation obtained from multiple edges due to reflections from various objects. Zhang et.al [4] proposed front vehicle recognition, in which the context information of the images and machine learning method were integrated to improve the performance of recognition. The vehicle detection was carried out using histogram of gradient (HOG) which counted occurrences of gradient orientation in localized portions of an image. This method had good performance on the structural road, however the limitation was that this method could not work well in the case of bright light. SenMa et.al [5] proposed a vision optical flow based vehicle forward collision warning system for intelligent vehicle. The detection of vehicle in this work was done by frame difference method. The main advantage of this method was that it had well performance of recognizing moving objects without modeling the background. However, its limitation was that if the object pixel of sequence frames were not much different, the result of this method did not provided enough information to extract boundary object. Additionally, the authors further used Optical Flow algorithm to track a front vehicle from selected object and applied Harris algorithm, a corner detection, with Lucas and Kanade (LK) for determining the moving intention of the vehicle. Su et.al [6] designed a new tracking algorithm by fusing Kalman prediction and Mean Shift Search together for moving objects in Unmanned Aerial Vehicle. The results indicated that their proposed method was computationally inexpensive which was fit for aerial video surveillance. Fang et.al [7] proposed a real-time collision warning system which

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contained lane marking detection, vehicle detection, and vehicle distance estimation. For marking the lane, the authors used the Sobel edge detector and Hough transform. This work divided vehicle detection into two parts, i.e. one was for daytime detection and another one was for nighttime. In day time they made use of shadow detection and edge detection together. However, for nighttime they used Cr component of the YCrCb color model to verify the location of the vehicle. Experimental results showed that the system was well performed and stable. However, at night time the performance was not accurate. Zhang et.al [8] observed the main problem in front vehicle detection and tracking base image processing. This work used improved HOG (Histogram of Gradient) for feature extraction and recognized object by carrying on Adaboost classifier then applied the Kalman filter for multiple objects tracking and enhancement of the detection rate. Another finding from Li et.al [9] established object motion model for multiple object tracking based on Kalman filter algorithm to choose centroid and track window. The authors used the matching results of sequence frames as the measurement for updating the state prediction of Kalman filter. From the estimated result with detection information, their system were able to judge whether there was a block between objects. Dai et.al [10] presented an integrative approach to vision-based lane departure detection and collision warning system with overtaking vehicle detection (rear vehicle detection). For lane departure of this presented work, the authors used low-level image features, Hough transform, and Sobel for calculating the gradient. In the detection scenario, this work applied the shadow detection for daytime; however, for the nighttime they proposed a symmetry analysis technique to improve the detection rate. The evaluation had showed the effectiveness of their proposed work.

This paper proposes a front moving vehicle detection and tracking which is utilized shifting frame different method with edge detection. The combination of these two methods has more advantages than shadow underneath technique and it fills the important information for extracting boundary object. Additionally, the shifting frame means to reduce the computation and it is also well fed in the process of tracking. In order to track the front moving vehicle, this work makes use of Kalman filter which is a classic state estimation algorithm. There are two main advantages in application of Kalman filtering.

- Kalman filter provides the state prediction of position after the first detected object. This prediction result can be used for minimizing area of the detection for the next coming frame, This will lead to the reduction in computation, overcome the obstruction of noise, and less uncertainty of measurement.
- Kalman Filter provides the auto-correction state by using measurement which is obtaining by vision base detection to update the prediction state. Consequently, the predictor will provide an estimation of whereabout the object will appear in the next frame.

This paper is organized as follows. Section II describes an overview of the proposed system. Section III explains the proposed methodology on front moving object detection and tracking scenario. Section IV provides experimental setup and result. Finally, the conclusion is described in section V.

II. System Overview

Figure 1 shows a diagram of the proposed front object detection and tracking for collision warning system. The system contains two main parts. Firstly, the front object detection takes a video as an input then converts every frame of video to the grayscale image. After having selected the first frame, Region of Interest (ROI) segmentation is processed to define the road area of the video scene. Next, when the ROI has been done, three frame difference with Sobel edge detector algorithm is used to find the boundary object. Sequentially, the system utilizes morphological operation with blob detection for extracting features of the boundary. Finally, Kalman filter is applied for tracking in order to predict the position of the detected object.

III. Proposed Methodology

This section discusses about the procedure to detect and track vehicle in each video frames.

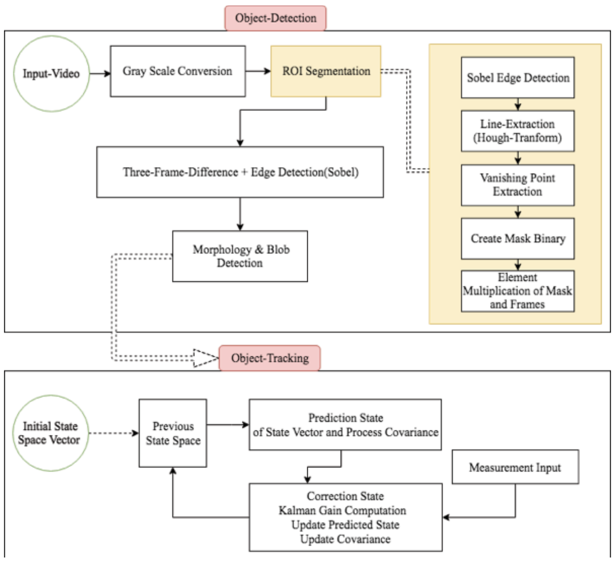


Figure 1. Vehicle detection and tracking system.

A. Front Moving Object Detection

Front moving object detection for collision warning system is a technique used to find front vehicles which appear in the monitoring zone of each frame in a video. The proposed detection method has four main partial steps which are described as follows:

1) Segmentation of ROI (Region of Interests): First of all, Sobel edge detection algorithm is applied for detecting all edges on the grayscale converted image. The Hough transform technique which prominently explains in [10]-[11], is then used to detect the lines. After that, the system is able to extract the left and right lines which are connected to the vanishing point. Since the left and right lines of the road always appear on the lower part of the input frames, only the middle bottom of the input frames is necessary for the Sobel edge operator and Hough transform for finding the lines. The upper part of the input image frame is cut for the reason of noises effect avoidance and computational load reduction. Figure 2(a) is the original input image with the upper part is removed and Figure 2(b) shows the corresponding edge detection result of Sobel operation. After having applied the Hough transform technique on the detected edges, those lines are judged to be the left or the right side of the frame in which rely on the equation (1) and (2).

$$\left(x_1 > \frac{w}{2}\right) \& \left(x_2 > \frac{w}{2}\right) \& \, \theta \in [-83, -20] (Right\ Line) \quad (1)$$

$$\left(x_1 < \frac{w}{2}\right) \& \left(x_2 < \frac{w}{2}\right) \& \, \theta \in [20,\ 83] (Left\ Line) \quad (2)$$

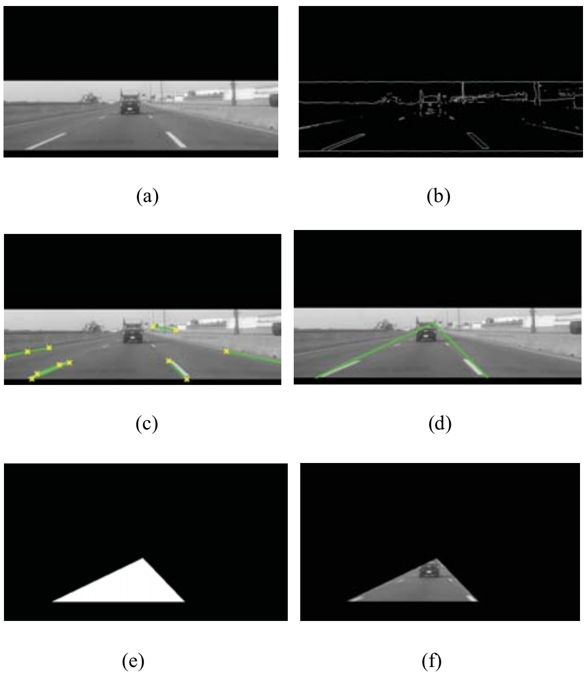


Figure 2. Simulation result.

Where x_1 and x_2 are the x-components of (x_1, y_1) and (x_2, y_2) which are the start and the end points of a line, w is the width of the input frame and θ is the angle resulting from Hough transform technique.

Based on these criterion, the system generates the left and right lines of the input frame. However, two of those lines are selected to be on each side. In this case, the system will choose the best right and left line by utilizing the third component of cross product vector which identifies the leftmost or the rightmost of the lines as shown in equation (3).

$$S = (x_m - x_1)(y_2 - y_1) - (y_m - y_1)(x_2 - x_1) \quad (3)$$

where (x_m, y_m) is the midle point of another line on the same side. If S < 0 then the point lies on one side of the line, and if S > 0 then it lies on the other side. If S = 0 then the points lies exactly line.

The vanishing point is the intersection of the left and right lines which are extracted from the input frame. According to both lines and vanishing point, the system is then able to mark the interest region of the frame as shown in Figure 2(d).

The next process is to generate the targeted region from the marking area. In order to generate the required area, a reference binary image (mask binary) is created, then the ROI is shaded white and the leftover region as black, as indicated in Figure 2(e). In order to obtain a mask binary, this work makes use of cross product vector which satisfies the condition that if the coordinates of the image pixel are in the selected area, those pixels are then set to 1 else they are set to 0. Finally, the multiplication of each element of the image with the mask results in the final desired target area which is illustrated in Figure 2(f).

2) Three Frame Difference with Edge Detection Method: After having extracted the ROI, the system applies three frame difference method to find the front moving object. Let $f_{k-1}(x,y)$, $f_k(x,y)$, and $f_{k+1}(x,y)$ are the consecutive grayscale images where x, and y are the coordinates of input frame, then the algorithm is specified in equation (4) and (5).

$$f_1' = \begin{cases} 1, & |f_k(x,y) - f_{k-1}(x,y)| \geq T \\ 0, & |f_k(x,y) - f_{k-1}(x,y)| < T \end{cases} \quad (4)$$

$$f_2' = \begin{cases} 1, & |f_{k+1}(x,y) - f_k(x,y)| \geq T \\ 0, & |f_{k+1}(x,y) - f_k(x,y)| < T \end{cases} \quad (5)$$

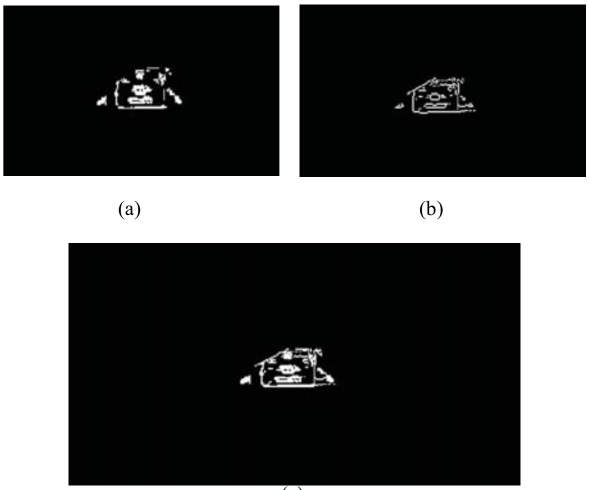
$$f'(x,y) = f_1'(x,y) \cap f_2'(x,y) \quad (6)$$

$$D(x,y) = f'(x,y) \cup D_k(x,y) \quad (7)$$

where f_1' and f_2' are the binary images resulting from consecutive substraction. f' is the final output of an intersection operation as shown in equation (6) and the result is illustrated in Figure 3(a). Since the three frame difference method produces an object without edge information, this paper utilizes the Sobel edge detector on the selected area. Equation (7) shows the combination of three frame difference and edge detector where $D_k(x,y)$ defines the edge detection of image frame $f_k(x,y)$. Therefore, the system has adequate information to extract the boundary object.

Figure 3(b) illustrates the result of Sobel edge detection, and Figure 3(c) shows the result of three frame difference with edge detection.

3) Extracting Boundary Object: In the proposed work, the system extracts boundary object by utilizing blob detection with morphological operation. Morphology is a mathematical image processing operation which operates images based on geometrical structures. This operation is to carry on removing noise and adding pixel for improving the information of shape in image. The proposed study makes use of the morphological dilation operations due to the object's pixels obtained from the detection are not well enclosed. Equation (8) shows the implementation of morphological dilation operation.



(a) (b) (c)

Figure 3. Simulation result of three frame difference with edge detection.

$$g = f \oplus s \tag{8}$$

Where g is the output image, f is input image, and s is the structure element. Figure (4) shows the image result obtained after applying morphological dilation operation.

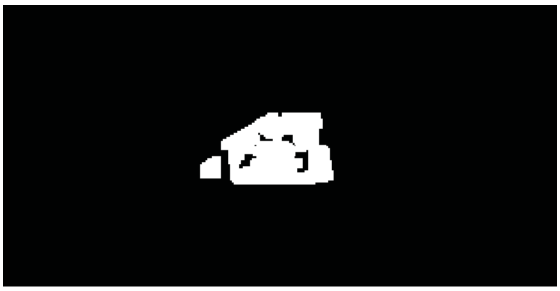


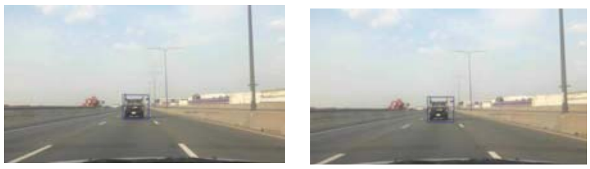
Figure 4. Simulation result of morphology operation.

Blob Detection is a method which aims to find the region differed in properties, such as brightness or color, compared to surrounding regions [12]. In this case, the authors use the white pixel value as the boundary object. Since the pixels value of every frame in a video scene are dynamically changed, the noises still exist even though morphological dilation is applied. Such reason, this work uses three main attributes, i.e. a ratio value between perimeter and round length of object's bounding box, a ratio value between object's area and the bounding box's area, and an object's area value to extract the true boundary object. Figure 5(a) shows a result of blob detection in a binary image. Since one-third of the real object in a video is cut for the reason of region of interest (ROI) selection, the threshold value is added to the height of the object's bounding box as illustrated in Figure 5(b).

(a) (b)

Figure 5. Result of blob detection in binary image and video's image.

4) Shifting Frame: The main purpose of shifting frame is to reduce the computational load of the system due to processing on the real-time environment. However, to select the number of shifting frame is based on the frame rate of the input video and also the collision time interval over the frames. In this work the interval is shifted by 5 frames because in the experiment the frame rate of videos are 25 frame per second (fps). Additionally, the system also monitors the collision time before 2s for driver reaction, as a result; the proposed system has sufficient time for computing and alerting the driver to react on time to the situation. Figure (6) illustrates the result of detection by shifting 5 frames.



Frame-5th frame-10th

Figure 6. Result of detection with shifting 5-fames.

B. *Object Tracking with Kalman Filter*

In the proposed research scenario, it is assumed that the front moving vehicle will only appear in the region of interest (ROI) which describes in the above section. Therefore, a single object tracking is established.

Mathematically, Kalman filter is a recursive least square estimator which predicts and automatically corrects the states [13]-[14]. The predicted state uses the model system equations which is based on the behavior of front moving object and previous state matrix, then the next state object parameter is predicted. When the time updating arrives Kalman filter takes the measurement resulting from the detector to update the prediction state for estimating the position of object.

Assuming that, a tracking system where X_k is the state vector represents the front moving object, such that k indicates the discrete time over frame interval. The main purpose of this tracking is to estimate the optimal X_k which updates by the measurement z_k. Following the description, Kalman filer involves two main stages which are prediction and measurement update as correction state.

1) Prediction Equations: Assumed that the initialization of parameters of state vector has been done, the prediction equations are given as follow:

$$\text{Prediction State}: \hat{X}_{k|k-1} = F_k \hat{X}_{k-1|k-1} + W_k \quad (9)$$

$$\text{Process Covariance}: \hat{P}_{k|k-1} = F_k \hat{P}_{k-1|k-1} F_k^T + Q_k \quad (10)$$

F_k defines the transition matrix which applies the effect of every state parameter. W_k is a zero mean white prediction noise with covariance Q_k. $\hat{P}_k$ is process noise covariance between terms in the state vector.

2) Correction Equations: At this stage Kalman filter computes the kalman gain, the ratio between covariance of noise prediction and covariance of noise in measurement. Then the prediction model is updated.

$$\text{Kalman Gain}: K_k = \hat{P}_{k|k-1} H_k^T \left(H_k \hat{P}_{k|k-1} H_k^T + R_k\right)^{-1} \quad (11)$$

$$\text{Measurement:} \quad z_k = H_k X_k + v_k \quad (12)$$

$$\text{Correction State}: \hat{X}_{k|k} = \hat{X}_{k|k-1} + K_k\left(z_k - H_k \hat{X}_{k|k-1}\right) \quad (13)$$

$$\text{Update covariance}: \hat{P}_{k|k} = (I - K_k H_k) \hat{P}_{k|k-1} \quad (14)$$

Where H_k is the measurement matrix and v_k is a zero mean white measurement noise with covariance R_k.

C. Kalman Motion Model for the Target Object Tracking

Describing the parameters of object moving on two dimensional image can be done by defining the coordinate of center, size, and velocity of object. Since position, size, and velocity of a vehicle in Kalman filter are represented by (x, y), (l, h), and (v_x, v_y, v_l, v_h) respectively, the state vector is then expressed $X_k = (x_k, y_k, l_k, h_k, v_{x_k}, v_{y_k}, v_{l_k}, v_{h_k})^T$. Since the measurement consists of position and size of the object, the measurement vector can be expressed $z_k = (x_k, y_k, l_k, h_k)^T$. Followings are the transition matrix F_k and measurement matrix H_k of the tracking system which are specified in equation (15) and (16). Finally, The Kalman filter based on the scene is established.

$$F_k = \begin{bmatrix} 1 & 0 & 0 & 0 & \Delta t & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & \Delta t & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & \Delta t & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & \Delta t \\ 0 & 0 & 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \quad (15)$$

$$H_k = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 & 0 & 0 \end{bmatrix} \quad (16)$$

D. Time Life-Cycle of Vehicle Tracking

The main objective of the time-life-cycle of vehicle tracking is to monitor the front moving vehicle such that the vehicle might be lost from the vision or it might be replaced by other vehicles. With this problem, the proposed work sets the monitoring process to verify each status condition of the tracking procedure. Figure (7) shows that after having first detected the front object, the system sets the status in a stack as appeared and begins initialization of state parameters for the tracking process. This iterate process is verified by the measurement output. If the verified condition is true, the system then sets the status as tracked else the system sets the status as lost. In order to check the status properly, the first loss of status tracking is not yet set to be disappeared unless the system cannot verify for tracking twice in a view. In this case, the system clears up the stack and starts detecting the object over the next time frames. Furthermore, at the first detected object, the prediction value is used for minimizing the ROI. This is not only leading to the reduction in the error of the detection rate but it also reduces the computational load as in Figure (8) shows the data flow of using the prediction value $x_{k|k-1}$ for minimizing the ROI and the measurement value z_k is used to update the predicted state over the frames.

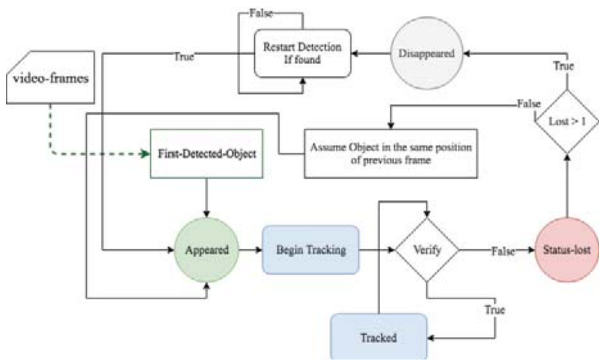


Figure 7. Life-cycle of detection and tracking of front moving object.

IV. Experimental Result

A. Experimental Set-up

The front moving vehicle detection and tracking system runs on MacBook Pro which has a 2.4 GHz Intel Core i7 processor with graphics Intel HD 4000 1536 MB and has 8 GB memory. The experiment of this system uses three different videos input as showing in table I. TF, R, FRP and NVDA are Total Number of Frames in a video, Resolution, Frame Rate Per-second, and Number of Vehicle in Detection Area respectively.

The first video is used as the sample of the data for initializing of the parameters of the state vector X_0, process covariance associated with the uncertainty of prediction model P_0, the noise covariance matrix of the prediction Q_k, and covariance of uncertainty in measurement R_k. The initialization of the parameters is done by manually selecting the center of object position over the 150 frames then computes the sum of squares error over the detected results. Then these initialized values are applied in other videos.

B. Result

Result of Object Detection: Since the system assumed that the front vehicle must be in the region of interest, the evaluation of detecting the object is then on the term of DR (Detection Rate), and FR (False Detection Rate) in the detection area. DN is the number of correction detection, and FN is a false number of detection. Table II shows the accuracy of detection before applying Kalman filter. However, the overall performance of detection is increase about 4.2% in average when Kalman filter is applied. Video 3 of Table II has high false detection rate due to the illumination of the light and roadside signs.

TABLE I. DESCRIPTIONS OF INPUT VIDEOS

Videos	TF	R	FRP	NVDA
1	150	720x1280	20fps	150
2	1300	720x1280	25fps	1000
3	1200	640x480	25fps	1200

TABLE II. EVALUATION OF DETECTION METHOD

Videos	DN	FN	DR	FR
1	137	13	91.33%	8.66%
2	921	56	92.1%	5.73
3	1064	123	88.66%	10.36%

$$DR = \frac{DN}{NVDA} \times 100\%$$

$$FR = \frac{FN}{DN + FN} \times 100\%$$

1) Result of Object Tracking: Figure (9) shows the result of object position which is tracked in video 2 and the shifting interval is 5-frames. This graph proves that the estimated values are adequate in real time vehicle tracking for collision avoidance system. Furthermore, Figure (10) demonstrates the results of tracking object window with the detection of shifting 5-frames in video 2. From the graph, the system is able to tell that in case the surrounding box of the object is getting smaller it means the object is moving away from the scene else the host object is closed to the front object.

V. CONCLUSION

This study observes the vision-based front moving vehicle detection and tracking approach using videos on urban structured roads in Thailand. This study predicts the next driving state of the front vehicle in order to increase driving safety by predicting the collision risk and warning the driver to avoid them. The works compose of two main scenarios which are front moving object detection and object tracking. In the detection process, the proposed study makes use of shifting three frame difference with a combination of Sobel edge detector algorithm. The shifting frame concept is to ensure that the system performs well in real-time scenario. According to the experimental results, the performance of detection and the correct detection rate are improved when the target object starts tracking with Kalman filter. For the tracking process, the system predicts the next state position and surrounding box of the object. This surrounding box is used to minimize the object area which helps the system to reduce the computational load and increase the detection rate. In overall, the system is well performed for the real-time detection and tracking for collision risk prediction. However, the proposed work might not be able to compare with the state of the art work dude to some limitations.

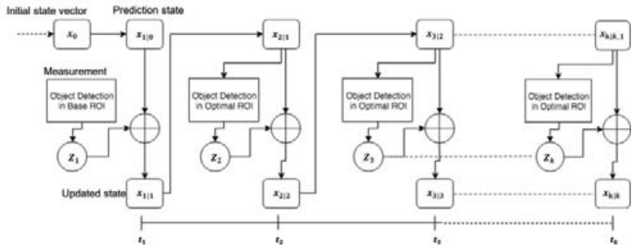


Figure 8. Data flow of kalman filter over time frame.

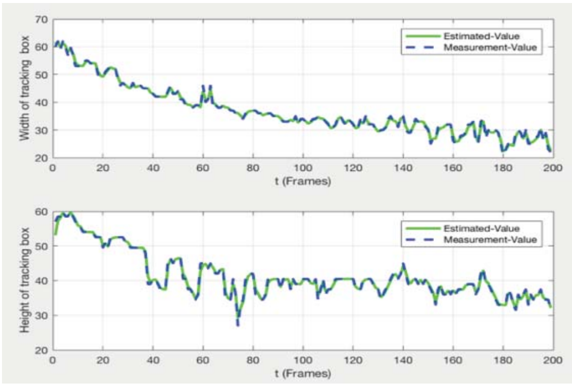


Figure 9. Result of tracking object position with shifting 5-frames of video 2.

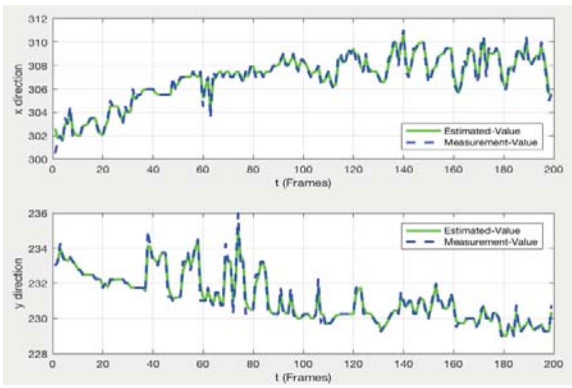


Figure 10. Result of width and height tracking with shifting 5-frames of video 2.

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REFERENCES

[1] J. Zhou and J. Hoang, "Real time robust human detection and tracking system," in *2005 IEEE Computer Society Conference on Computer Vision and Pattern Recognition (CVPR'05) - Workshops*, June 2005, pp. 149–149.

[2] S. Srilekha, G. N. Swamy, and A. A. Krishna, "A novel approach for detection and tracking of vehicles using kalman filter," in *2015 International Conference on Computational Intelligence and Communication Networks (CICN)*, Dec 2015, pp. 234–236.

[3] G. K. Yadav, T. Kancharla, and S. Nair, "Real time vehicle detection for rear and forward collision warning systems," in *Advances in Computing and Communications*, A. Abraham, J. L. Mauri, J. F. Buford, J. Suzuki, and S. M. Thampi, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2011, pp. 368–377.

[4] G. Zhang, F. Lin, and L. Lin, "A novel method of front vehicle recognition," in *2016 Progress in Electromagnetic Research Symposium (PIERS)*, Aug 2016, pp. 2126–2130.

[5] SenMa, S. H. Chen, C. S. Yang, S. C. Chu, and J. S. Pan, "Vision based front and rear vehicle collision warning system," in *2015 Third Interna- tional Conference on Robot, Vision and Signal Processing (RVSP)*, Nov 2015, pp. 22–26.

[6] B. Su, H. Wang, X. Liang, and H. Ji, "Moving objects detecting and tracking for unmanned aerial vehicle," in *Foundations and Practical Applications of Cognitive Systems and Information Processing*, F. Sun, D. Hu, and H. Liu, Eds. Berlin, Heidelberg: Springer Berlin Heidelberg, 2014, pp. 317–333.

[7] C. Fang, J. Liang, C. Lo and S. Chen, "A real-time visual-based front-mounted vehicle collision warning system," *2013 IEEE Symposium on Computational Intelligence in Vehicles and Transportation Systems (CIVTS)*, Singapore, 2013, pp. 1-8. doi: 10.1109/CIVTS.2013.6612282

[8] X. Zhang, H. Gao, C. Xue, J. Zhao, and Y. Liu, "Real-time vehicle detection and tracking using improved histogram of gradient features and kalman filters," International Journal of Advanced Robotic Systems, vol. 15, p. 172988141774994, 01 2018.

[9] X. Li, K. Wang, W. Wang, and Y. Li, "A multiple object tracking method using kalman filter," in *The 2010 IEEE International Conference on Information and Automation*, June 2010, pp. 1862–1866.

[10] J. Dai, L. Wu, H. Lin and W. Tai, "A driving assistance system with vision based vehicle detection techniques," 2016 Asia-Pacific Signal and Information Processing Asssociation Annual Summit and Conference (APSIPA), Jeje, 2016, pp.1-9.
doi:10.1109/APSIPA.2016.7820739

[11] Zheng, S. Luo, K. Song, C.-W. Yan, and M.-C. Wang, "Improved lane line detection algorithm based on hough transform," Pattern Recognition and Image Analysis, vol. 28, no. 2, pp. 254–260, Apr 2018. Available:https://doi.org/10.1134/S1054661818020049

[12] BLOB Analysis (Introduction to Video and Image Processing) Part1. Retrieved from http://what-when-how.com/introduction-to-video-and-image-processing/blob-analysis-introduction-to-video-and-image processing-part-1/

[13] M. Rhudy, R. A Salguero, and K. Holappa, "A kalman filtering tutorial for undergraduate students," *International Journal of Computer Science Engineering Survey*, vol. 08, 2017.

[14] Y. Pei, S. Biswas, D. S. Fussell, and K. Pingali, "An Elementary Introduction to Kalman Filtering," *ArXiv e-prints*, Oct. 2017.