



TRAFFIC MONITORING AND EVENT ANALYSIS BASED ON INTEGRATED MULTIVIDEO AND PETRI NET PROCESS

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Key words: traffic monitor, intelligent traffic system, Petri net, motion detection.

ABSTRACT

Decreasing traffic accidents and events are one of the most important responsibilities for all of the governments in the world. However, it is difficult to exactly measuring the traffic condition. To find out the root cause of traffic accidents and restore the occurrence of traffic events, a traffic monitor and event analysis mechanism based on multi-videos processing and Petri net analysis techniques is proposed. In which, the traffic information is collected through the deployment of cameras at intersection of heavy traffic area. After then, all of the collected information is provided for constructing multi-viewpoint traffic model. The significant features are extracted for traffic analyzing through Petri Net and detection of motion vector. Finally, decision is output after integrated traffic information and event analysis. Experimental results demonstrate the feasibility and validity of our proposed mechanism. It can be applied as a traffic management system.

I. INTRODUCTION

As the technique emerging, the necessity of establishing an intelligent life has become very popular and strongly advocated. Thus, the physical construction of ITS (intelligent traffic system) through traffic monitoring and management has become a significant issue in most of the countries. The goal is to decrease the occurrence of traffic incidents. Therefore high resolution video cameras have been mounted on all of the freeways, heavy traffic highways, tunnels and important traffic intersections of the main cities to monitor and detect the traffic condition. In addition, the related information can be supplied as the evidence for traffic enforcement.

In the past few years, the fact is most of the traffic condi-

tions are difficult to predict. But, as the scientific techniques emerging, traffic flow management becomes easier than before. In addition, some mobiles have mounted with high resolution camera to provide early warning and avoid accidents. The infrastructure for monitoring and managing the traffic at freeway, heavy traffic highway, main traffic intersection or tunnels has obviously improved and gradually accomplished in most of the critical cities worldwide. However, as regarding the early warning systems or traffic restoration system, the development of related applications and products is still a must.

Life is uncountable treasure. That is the reason that all of the drivers are tried to drive carefully as possible as they can. However, there still traffic accidents occurred every day. Therefore, well understand the behavior of drivers is very important. The goal of traffic management is not only focus on the detection of traffic events and flow control, but also focused on detecting those aggressive and violating drivers to decrease traffic accidents.

Regarding video surveillance for traffic detection, several researchers have developed some different types of video detection systems (VDS) [6]. In [11], Wang *et al.* proposed a video image vehicle detection system (VIVDS) to detect different color vehicles. In [4], Ki *et al.* proposed a vision-based traffic accident detection system based on inter-frame difference algorithm for traffic detection at intersections.

Although there are a lot of different types of VIVDS developed, single installed camera mounted on the poles of roadside or traffic light is not sufficiently to capture the entire intersection and provide the needed whole completely traffic information. Some evidences shown that even the popular advanced Traficon systems might have problem of false positive and false negative signals at the intersections due to the reason of weather and lighting conditions [6].

In order to understand the root cause of traffic accidents and restore the occurrence of traffic events, a traffic monitor and event analysis mechanism based on multi-viewpoint and 3D video processing techniques is proposed in this paper.

The rest of this paper is organized as follows. In Section II, the rationale of Petri Net and multi-viewpoint traffic model is introduced. Traffic monitor and event analysis are

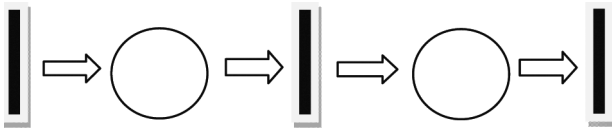


Fig. 1. Demonstrate a traditional graph of Petri Net.

addressed in Section III. Experimental results are demonstrated in Section IV to verify the feasibility and validity of our proposed mechanism. Finally, concluding remarks are given in Section V.

II. RATIONALE OF PETRI NET AND MULTI-VIEWPOINT TRAFFIC MODEL

1. Rationale of Petri Net

Generally, a Petri net [8] is defined by variables such as place, transition, and directed arc to express their relation and flow and transition status. In which, an arc represents the variation and only runs from a place to a transition or from a transition to a place. It will not run between places or between transitions. A traditional graph of Petri Net is shown as Fig. 1.

The graph of Petri Net graph applied in this paper is a 5-tuple (S, T, W, I_0, M) for each vehicle. To correctly analyze the vehicle's route, monitor and indicate their location is the basis foundation. In addition to indicate the vehicle location with the relative coordinate location on each frame, the vehicles will be assigned another coordinate information as they were driven into the monitored intersection area, no matter there is only part of the vehicle is intersecting with the monitored intersection area. Therefore, as the vehicles enter into the monitored intersection area, the manipulation of its center of gravity of each vehicle will not only calculated based on the location of each frames. Another index of center of gravity manipulated based on the exact intersecting parts of each vehicle within the monitored intersection area will be added for further analysis.

The center of gravity of each vehicle is computed based on Euclid distance. In which, the point that possesses the smallest distance difference from all of the other points of the vehicle will be selected as the gravity center. Shown in Eq. (1) is the manipulation of gravity center (V_x, V_y) of each vehicles, where TP is the total pixels of a vehicle in a frame and V_x and V_y are the coordinate of vehicle position corresponding to the X-axis and Y-axis in each of the frame. Moreover, V_{ix} and V_{iy} represent the coordinate position of vehicle in the i^{th} frame.

$$(V_x, V_y) = \text{Min} \sum_{i,j} \frac{\sqrt{(V_{ix} - V_{jx})^2 + (V_{iy} - V_{jy})^2}}{TP} \quad (1)$$

As for an intersection area, the coordinate of gravity center is defined as S_x in X-axis and S_y in Y-axis. To manipulate

Table 1. Record of vehicle information

Token ID	frame number/video number	center of gravity on frame		center of gravity within intersection area	
		V_x	V_y	S_x	S_y
1/Bus	11/1	317	165	309	176

the gravity center within an intersection area (S_x, S_y) , it is computed according to Eq. (2). In which, the ITP is the total pixels of a vehicle that located inside the intersection area in a frame.

$$(S_x, S_y) = \text{Min} \sum_{i,j} \frac{\sqrt{(V_{ix} - V_{jx})^2 + (V_{iy} - V_{jy})^2}}{ITP} \quad (2)$$

In order to simplify the manipulation of gravity center of a vehicle and decrease the needed computing time, if a vehicle is driven straight or very close to form linearly, the relative gravity center of a vehicle will keep as the same position corresponding to the whole shape of a vehicle. Shown in Table 1 is a sample of the recorded information for vehicles.

All of the parameters of the Petri Net utilized in the paper are defined as the following:

- (1) Parameter S represents a finite set of places that vehicle located within the intersection of each frames of the traffic video. The coordinate information of the intersection area will be on the same coordinate system with the frames of the taped video. In which, the top left corner of the frame is assigned as the original referring coordinate point $(0, 0)$. In the beginning phase, the center of gravity of each vehicle might not be the true center due to the vehicle is not coming into the monitored area completely. After then, as the shape of vehicle completely located inside the monitored area, the center of gravity of each vehicle will become more stability.
- (2) Parameter T represents a finite set of transitions that represent the variation of each vehicle. As for those vehicles that go straight through the monitored area, their variation will be easier to trace and most of their route will form similar as linear straight line. Otherwise, for those vehicles that ready to take left turn or right turn, the variation of their transition might form a curve.
- (3) Parameter W represents a multi-set of arcs. It is defined and operated as Eq. (3).

$$W: (SxT) \cup (TxS) \rightarrow N \quad (3)$$

where \cup is the operation of Union. In this operation, arcs will be defined. Besides, each arc will be assigned with a non-negative integer.

- (4) Parameter I_0 represents the initial state of each vehicle

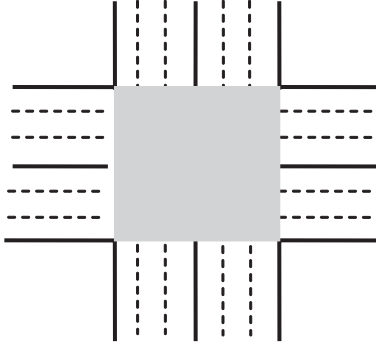


Fig. 2. Illustrate the focused traffic intersection for applying Petri Net analyzing.

that has been detected inside the monitored intersection area.

- (5) Parameter M represents the marking of the Petri net graph for each vehicle. The marking is a multi-set of places in the Petri net graph. In which, a mapping process is performed as Eq. (4).

$$M : S \rightarrow N \quad (4)$$

The marking is assigned to each place a number of tokens. In which, M_0 is the initial marking. As the vehicles enter into the monitored intersection area, each vehicle will obtain a token ID. This token ID only validate as the vehicle stay inside the monitored intersection area. As the vehicle move away from this monitored area, the token ID expired and will be reused and agined to another new vehicle that entering into the monitored area.

All of the 5-tuple is assigned and validated only as the vehicle enters into the area of focused traffic intersection blocks as shown in Fig. 2.

The application of Petri Net analysis for traffic is based on the vehicular route and interactivity. In order to correctly and exactly detect the mutual interactivity of vehicles inside the monitored intersection area, autocorrelation and cross-correlation manipulation will be applied for further analysis.

(1) Autocorrelation measurement [1]: The detecting results belonging to each vehicle will be provided for autocorrelation measurement. The input data for manipulation is the entire information collected from the 5-tuple information of Petri net. The measurement of autocorrelation, A_r , for each independent vehicle is computed as Eq. (5).

$$A_r(S_i, S_j) = \frac{E\left[(S_i - m_{S_i})(S_j - m_{S_j})\right]}{\sigma_{S_i} \sigma_{S_j}} \quad (5)$$

In which, S_i represents finite set of places in the i^{th} frame and m_{S_i} is the mean and σ_{S_i} is the variance in the i^{th} frame.

(2) Cross-correlation measurement [3]: The detecting results collected from each vehicle will be provided for cross-

correlation manipulation. The input data for manipulation is the entire information collected from the 5-tuple information of Petri net. The measurement of cross-correlation, C_r , between different vehicles is computed as Eq. (6).

$$C_r(A_u(S_i), A_v(S_j)) = \frac{E\left[(A_u(S_i) - m_{A_u(S_i)})(A_v(S_j) - m_{A_v(S_j)})\right]}{\sigma_{A_u(S_i)} \sigma_{A_v(S_j)}} \quad (6)$$

In which, $A_u(S_i)$ represents the i^{th} frame of the u^{th} vehicle and $m_{A_u(S_i)}$ is the mean and $\sigma_{A_u(S_i)}$ is the variance of the i^{th} frame of the u^{th} vehicle.

After the vehicle shaping, the center of each shape represents the current place of that vehicle and its driving route will then be detected. As the vehicles come over into the intersection area which indicated by gray color as shown in Fig. 2, each vehicle will be assign a token and the token is validated only inside the intersection area. In order to record the timestamp of each token, the token's timing will be set synchronously with the fps (frames per second) of video displaying. As the vehicle move outside of the intersection area, the validation of the token will be expired. Under normal situation, each vehicle pass through the intersection area only as its driving direction's green light is turning on. No matter the vehicle is going straight or taking left turn and even right turn, it has to wait for the validated indicating traffic light. Normally, most of the inner lanes will be reserved and marked for those vehicles that needed to take left turn and the other lanes are used for driving straight or taking right turn.

2. Rationale of 3D Video and Multi-viewpoint Traffic Model

To record dynamic visual events, multi-viewpoint is an ultimate image media [7] in the real world. For example, one can record 3D object shape with high fidelity surface properties such as color, shape, or texture according to time varying sampling.

In [5], Matsuyama *et al.* proposed a 3D video processing model, in which some techniques are developed as the following:

- (1) First of all, reconstruct dynamic 3D object action from multi-viewpoint video images in real-time.
- (2) Reconstruct accurate 3D object shape by deforming 3D mesh model.
- (3) Render natural-looking texture on the 3D object surface from the multi-viewpoint video images.

Shown in Fig. 3 is the demonstration of sensors deployment at the intersection of a road. In the figure, the red spot indicates a virtual target for cameras to focus on and record the related information based on time varying sampling. The yellow arrows represent the deployed cameras and their recording direction. How many cameras will be optimal for

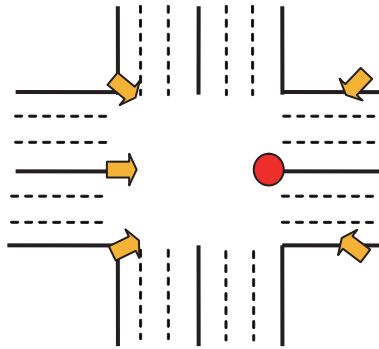


Fig. 3. Demonstrate the deployment of sensors at the intersection of a road.

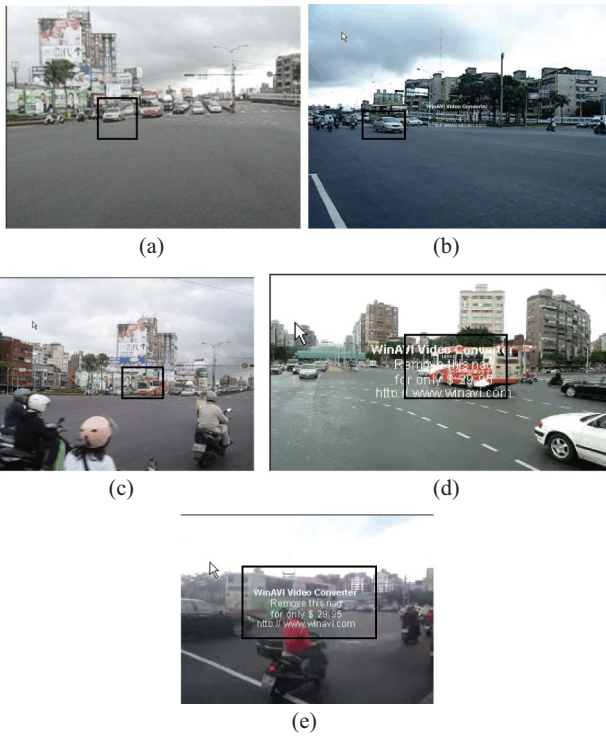


Fig. 4. Illustrate the recorded frames in one of the traffic intersection from 5 different directions according to Fig. 3.

dispatching to record the real traffic condition is left for implementation-defined. The reason is because there are not any intersections which will be under the same traffic situation. But, at least 4 to 5 will be better for constructing multi-viewpoint traffic model. In addition, each dispatched sensors must possess the same specification such as the same color display and calibration system, resolution, and etc.

Shown in Figs. 4(a) to 4(e) are the illustrations of frames recorded in the same traffic intersection area from different viewpoints according to Fig. 3. In which, the same bus in different frames that extracted from videos recorded in different direction are marked by rectangular blocks.

To construct perspective multi-view from multi-videos, the procedure is stated as the following:



Fig. 5. The diagram of preprocessing lists for traffic video.

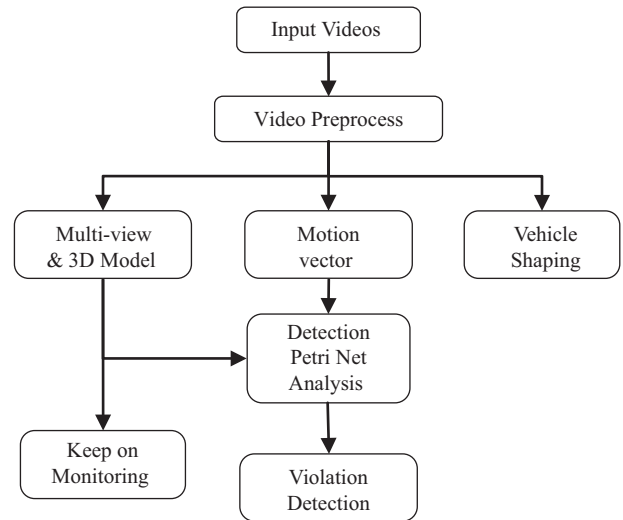


Fig. 6. Demonstrate the flowchart of traffic video processing.

- Step 1: Evaluate the importance of a traffic intersection.
- Step 2: Decide how many cameras would be sufficient and suitable for deploying to collect the needed information for construct multi-viewpoint traffic model.
- Step 3: Determine the mounted location.
- Step 4: Record the physical traffic information from different directions such as the viewpoint from front-side direction, the viewpoint from right-hand side direction at the front and rear position, and the viewpoint from left-hand side direction at the front and behind position.
- Step 5: Perform video pre-process such as noise cleaning.
- Step 6: Integrate all of the data and construct 3D traffic video or multi-viewpoint traffic model.

III. TRAFFIC MONITOR AND EVENT ANALYSIS

1. Preprocess of Traffic Videos

To completely comprehend the real traffic condition, correctly perform the desired traffic detection is a must. Therefore, all of the camera must be stationary allocated at selected optimal places. Besides, to exactly analyze the driving behavior of each vehicle under the monitored traffic area, the raw traffic video has been applied for preprocessed to reduce those unwanted interference information or even noises. In this paper, most of the frame size of videos recorded are set as 720*480. The diagram for preprocessing of traffic video is shown in Fig. 5. The completely flowchart and different modules for traffic video process is shown in Fig. 6. The

detailed traffic videos process procedures are addressed as the following.

- Step 1: The input video is decomposed into frames [12].
 Step 2: Noise cleaning has been performed to reduce those unnecessary noises. Especially, in order to exactly extract the vehicular information, noise cleaning must be performed after the operation of background subtraction process of decomposed frames [10].
 Step 3: Background segmentation is performed for further processing such as vehicular information extraction and vehicle tracking.
 Step 4: In this step, three tasks have been performed including multi-viewpoint traffic model construction, 3D Video presentation, motion vector detection, and vehicle detection by applying Fourier descriptor (FD) for vehicle shaping, representation, recognition and further tracking [2, 13].
 Step 5: Petri Net has been performed for status tracking for each vehicle. In addition, integrated traffic information are analyzed in this step.
 Step 6: In this step, two tasks have been performed including violation detection and continuing to monitor and record the traffic. In which, the module of violation detection is determined from those information generated in step 4. In addition, the proposed mechanism will keep on monitoring and recording the following traffic condition.

2. Combination of Petri Net and Motion Vector Analysis

The recorded Petri Net information of each vehicle will be collected and combined with the motion vector of each vehicle for integrated analysis. Shown in Fig. 7(a) is one of the traffic video recorded at Taipei city. In this frame, the red line marked is the intersection area. This video possesses 124349 frames which is taped from the front side direction with size 720*480. Shown in Fig. 7(d) is the motion vector detected from Fig. 7(c) which is the 5th frame of the video. Shown in Fig. 7(f) is the motion vector detected from Fig. 7(e) which is the 11th frame of the video. Both of the motion vectors are detected inside the traffic intersection area in different timing.

As shown in Fig. 7(b), this figure is the 11th frame of the taped video. In which, there are 4 vehicles marked by red rectangular which are located inside the intersection area.

The detailed information recorded according to frame number is tabulated in Table 2. In which, the bus is assigned with Token ID 1, since it is the first vehicle that entered into the intersection area. The minivan is assigned with Token ID 2. The yellow color taxi is assigned with Token ID 3 and the black car is assigned with Token ID 4. Since both of the yellow color taxi and the black car are thoroughly located inside the intersection area, therefore their center of gravity on the 11th frame and the center of gravity within the intersection area are the same. However, as for the bus and minivan, their

Table 2. Vehicle information recorded in Fig. 7(b).

Token ID	frame number/video number	center of gravity on frame		center of gravity within intersection area	
		V_x	V_y	S_x	S_y
1/Bus	11/1	317	165	309	176
2/Minivan	11/1	261	152	256	157
3/Yellow color Taxi	11/1	159	224	159	224
4/Black car	11/1	69	193	69	193

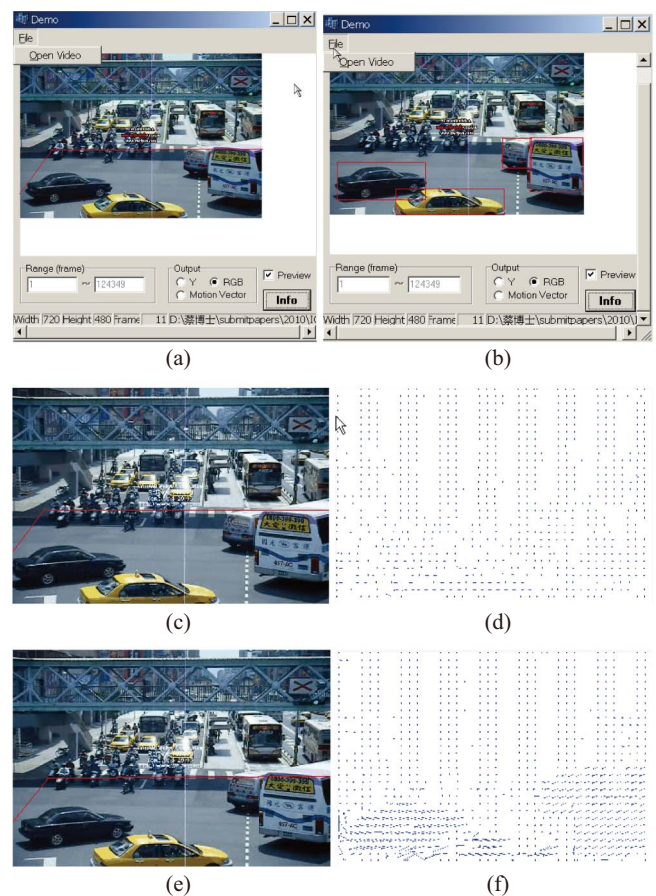


Fig. 7. Demonstrate the detected motion vector of traffic flows.

center of gravity on the 11th frame and center of gravity within the intersection area will be different.

Tabulated in Table 3 is the comparison of vehicle information of black car in different frames. In which, the coordinate position of center of gravity of black car within the intersection area in Fig. 7(c) is (61, 197) and the coordinate position of center of gravity of black car within the intersection area in Fig. 7(e) is (69, 193). The black car shown in Fig. 7(c) and Fig. 7(e), both possess the same center of gravity on the 5th and 11th frames and the center of gravity within the intersection area.

All of the vehicles moved on the same direction or took

Table 3. Comparison of vehicle information from different frames.

Token ID	frame number/video number	center of gravity on frame		center of gravity within intersection area	
		V_x	V_y	S_x	S_y
4/Black car	5/1	61	197	61	197
4/Black car	11/1	69	193	69	193

left-turn or right turn or even U-turn from other directions will also be collected and integrated for advanced analysis.

Through manipulation, the interactivities of each vehicle inside the same traffic environment or within the same monitored traffic intersection area could be applied to determine if a vehicle is categorized as possible aggressive, dangerous, or violating driving. In addition, if the motion of a vehicle is recognized as violating or aggressive, a violation message will be alarmed. Otherwise, this system will keep on monitoring and analyzing the traffic until there is violating or aggressive driving occurred.

The motion vector of each vehicle is measured based on the movement amount of macro-block with the most likelihood color and the highest similarity of vehicle shape traced by Fourier descriptor simultaneously to avoid false tracing induced by considering color only. Some examples are demonstrated as shown in Fig. 7(b) and Fig. 7(d). Moreover, the traffic light will also be considered as a feature to evaluate if there is any violation.

3. Diversity

Diversity techniques, which are widely used for combating multipath fading effects, can be implemented in many ways. In this paper, we adopt a relatively simple yet effective spatial diversity technique called equal gain combining (EGC). The EGC combines the received signals from multiple hydrophones at different spatial locations to form a signal with a higher signal-to-noise ratio (SNR).

IV. EXPERIMENTAL RESULTS AND DISCUSSION

1. Experimental Results

Shown in Fig. 8 are some images/frames extracted from traffic videos. Shown in Fig. 9(a) to Fig. 9(h) are some sequential frames extracted from the video which is recorded at the same intersection as shown in Fig. 8 from the right-side direction. In which, Fig. 8(c) is the frame extracted from front-side tapped video. Shown in Fig. 9(a), the traffic light of straight direction has changed to be green light. However, those vehicles that took left turn west to north direction such as the bus that marked by red line are still moving. In addition, some different vehicles just behind that bus and also keep moving.

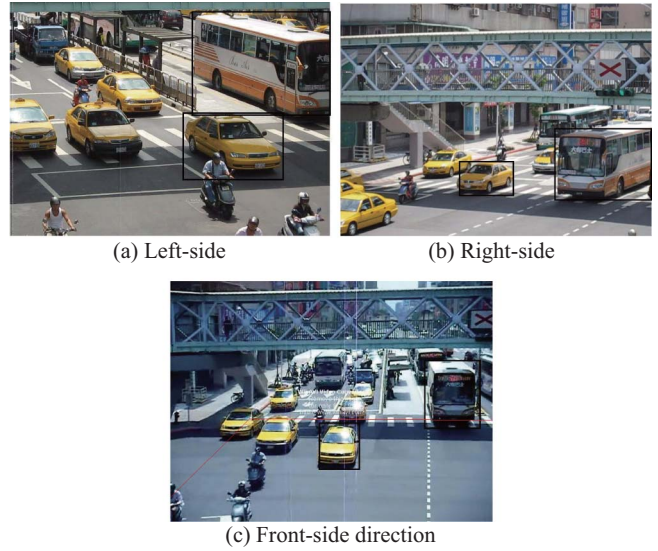


Fig. 8. Illustrate the video recorded from different viewpoint in different traffic intersection.

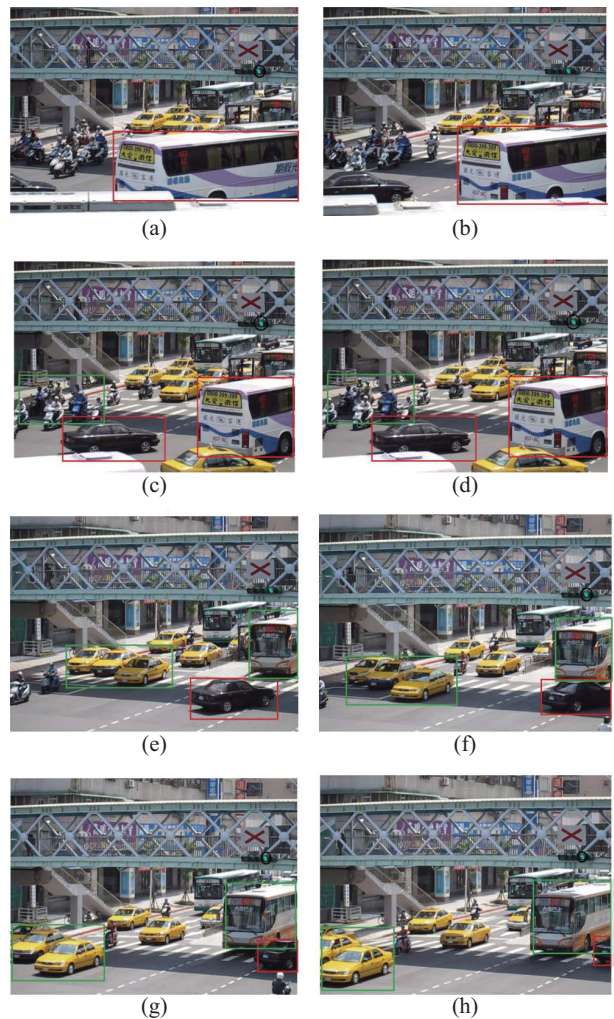


Fig. 9. Illustrate the extracted sequential frames that recorded at the same intersection as shown in Fig. 8 from the right-side.

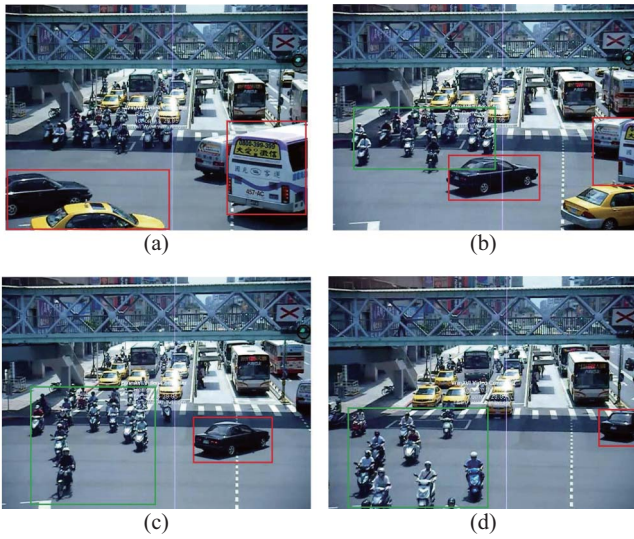


Fig. 10. Demonstrate the extracted frames that recorded in Figs. 8 and 9 from the front-side.

Shown in Fig. 9(c) and 9(d), one can clearly find that some motorcycles as marked by green line are moving straight forward from north to south direction, because their traffic light has already changed into green light. However, those left turn vehicles are still not yet finished their left-turn route. Shown in Fig. 10 are some frames extracted from the video which is recorded at the same intersection as shown in Fig. 8 and Fig. 9 from the front-side direction.

2. Discussion

By inspecting Fig. 9(c) to 9(h), one might suspect and can estimate that some vehicles might run over red light as they took left turn from the west direction to the north direction. The behavior of those vehicles is quiet dangerous and aggressive to straight route vehicles. If there is only single camera/sensor monitored, it is difficult to make judgment and well comprehend the real traffic situation. Fortunately, in the paper, 3 cameras have been mounted and recorded the traffic from 3 different directions. Therefore, the exact traffic can be completely established or restored. Moreover, those violated vehicles will be enforced.

In order to avoid traffic incidents, the process of motion vector has been adopted in the paper. Therefore, one can easily extract the exact route of each vehicle from the 3 different tapped videos.

To construct 3D traffic video, the difficulty is much higher than construct 3D images for static object. Because, the traffic information is recorded from time varying system, therefore the techniques for improving the process of image compensation and interpolation are significantly affect the final performance. As regarding the construction of 3D traffic model for the necessity of presenting from different viewpoint, some works had better be well prepared such as the following:

- (1) A lot of videos should be taped from different viewpoints to focus on a same object.
- (2) Collecting as much information as possible to avoid the problem of information insufficient. The tapping directions must at least include the viewpoints from forward direction, right side direction, and left side direction.
- (3) The 3D model of an object could be constructed through fragile segmented images.
- (4) Compensation techniques must be applied to remedy the insufficient information for 3D model construction.

Since the goal of constructing multi-viewpoint traffic model and 3D video automatically, therefore the preprocessing of image normalization and compensation for those extracted frames are quiet important. That is because the results of preprocessing will significant effect the following construction of 3D video. In addition, well process of interpolation is another quiet important key factor for optimal presenting the real traffic environment. Moreover, the decision for image segmentation might be a tough task in the automatic process. Therefore, the quality of preprocessing must be strictly required.

There are also some problem that needs to improve for traffic analysis. One is the issue regarding real-time manipulation. Since the manipulation of motion detection and gravity center do take times, it is difficult to speed up the computation based on single microprocessor. Therefore, systems with multi-core microprocessor or multiprocessors might be better choice. Moreover, there are a lot of motorcycles driven in the street of main cities in Taiwan. The tracking of motorcycle is not difficult. However, shaping the motorcycle independently is not an easy job. Due to they possess less pixels representation and most of their driven route are very closely or even mixing together. In addition, their driven routes are formed nonlinear. The third problem is the minimization of shadow. As for bigger vehicles such as bus, minivan, or cars, to minimize the shadow and isolate the shadow part from the manipulation of gravity center will be easier by utilizing background subtraction. However, this is also an annoying problem as for managing the process of motorcycles.

V. CONCLUSION

To decrease the traffic events and prevent the occurrence of traffic accidents are one of the important responsibilities of the government for all of the nations in the world. Since most of the heavy traffic bottlenecks occurred within the main traffic intersection area, highways, freeways and etc., therefore a lot of traffic monitor systems or earlier warning systems are mounted on those important areas. However, there are still a lot of traffic occurred every day. No government agents could precisely and exactly provide a system to dramatically cut down or even stop the occurrence of traffic events or accidents.

In order to correctly find out the root cause of traffic acci-

dents, restore the completely process of the occurrence of traffic events and exactly understand the key factor of traffic management, a traffic monitor and event analysis mechanism based on multi video for establishing 3D video processing are introduced in this paper. In the proposed scheme, there are three modules named as information collection, multi-viewpoint traffic model and 3D video process, and expert system. The traffic information are recorded and collected through the deployment of a lot of video monitors around each intersection of those heavy traffic areas along five directions where 3 directions are from front, right-front, and left-front directions and 2 directions are from rear-left direction and rear right direction. Therefore, each vehicle is monitored by many detectors. All of the collected information is transferred to the 3D process for constructing the 3D model based on the options such as vehicles, directions, time factor, and etc. Those significant features for traffic analyzing are also extracted and retrieved in this module. In addition, rationale of Petri Net is adopted for vehicular tracking and interactivity analysis. Finally, the expert module is responsible for integrated traffic information and event analysis and offering decision making such as the application of early warning or enforcement. Experimental results demonstrate the feasibility and validity of our proposed mechanism. However, to construct 3D traffic video, the difficulty is much higher than construct 3D images for static object. That is because the traffic information is recorded based on time varying system. In order to present traffic in 3D model, the future work will be focused on the improvement of image normalization, compensation and interpolation process.

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