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Traffic Light Recognition and Dangerous Driving Events Detection from Surveillance Video of Vehicle Camera

Haike Guan, Ryosuke Kasahara, Tomoaki Yano;
Ricoh Institute of Information and Communication Technology, Ricoh Co. LTD.;
Yokohama/Japan

Abstract

Surveillance video of vehicle camera are widely used to support driver's safe driving, especially for taxi and truck drivers. Long-term videos are often inspected by human operators manually to find dangerous driving events, which is tedious time consuming work. We propose a new method to detect dangerous driving events automatically from the surveillance videos. Events such as rocket start, red light ignored dangerous driving can be detected. In our method, traffic light recognition is made at first. Then speed and acceleration data of car, traffic light recognition results are used as features to detect dangerous driving events.

Color and shape of traffic lights are different in different countries and areas. Color and shape of traffic light images are also different at different shooting time, background and weather condition. It is difficult for conventional method to obtain both high recognition rate and low false positive rate. We proposed to use color, shape and context features to recognize traffic light more accurately.

Vehicle road testing in both USA and Japan were made to demonstrate effectiveness of our proposed method. Real-time processing recognition experiments were made by vehicle camera video stream. Surveillance videos taken by driving recorder camera were also used to do traffic light recognition and dangerous driving events detection experiments. Traffic light recognition rate of 93%, false positive detection rate of 0.1%, real-time processing time less than 30ms results were obtained by our method.

Introduction

Surveillance videos of vehicle camera are widely used to support driver's safe driving, especially for taxi and truck drivers. If dangerous driving events are found from the videos, drivers are advised to improve their driving style and skill. Insurance companies also use the surveillance videos of vehicle camera to confirm driver's driving record. If the driver drives safely, the company will reduce his insurance fee. Long-term videos are often inspected by human operators manually to find dangerous driving events, which is tedious time consuming work. Detecting dangerous driving events automatically can help the inspectors to check the surveillance videos easily. Detecting dangerous driving events in real-time can also alarm the diver to prevent traffic accidents on time.

We propose a new method to detect dangerous driving events automatically from the surveillance video of vehicle camera. Events such as rocket start, red light ignored dangerous driving can be detected. In our method, traffic light recognition is made at first. Then motion information of speed and acceleration data of the car, traffic light recognition results are used as features to detect dangerous driving events.

Related Work

Dangerous Driving Events Detection

Vehicle's inertial sensors data from the CAN bus of car is used to recognize driver's driving style [1]. Events of braking, acceleration and turning are detected from inertial sensors CAN data. Features associated with the events are used to classify drivers for reducing dangerous driving.

Vehicle velocity and acceleration data recorded by drive recorder are used to detect dangerous driving [2]. Braking pattern of the drivers are clustered by the sensor data. Five level dangerous driving events are recognized by using the braking pattern clustering results.

Sensor data of smartphone is used to detect driving events, such as turning, U-turns, acceleration, baking, excessive speed. Driving styles of aggressive and non-aggressive are recognized by features of detected events data [3]. Aggressive driving style is often related to dangerous driving. All of processing are made in the smartphone.

Although sensor data can be used to detect dangerous driving events, only limited kind events can be detected. It is difficult to detect dangerous driving events, such as rocket start and red traffic light ignored. Video data is useful for detecting more kinds of dangerous driving events.

Dangerous driving events detection by dual cameras on smartphone is proposed [4]. Dangerous driving conditions and behavior are detected to alert divers. Front-facing camera is used to monitor the driver to detect if he is tired or distracted. Rear-facing camera tracks road conditions to find dangerous driving events at the same time. Drowsy driving, inattentive driving are recognized by using front-facing camera's video stream. Tailgating, lane weaving and drifting, careless lane change dangerous driving events are detected by video stream of rear-facing camera. Computer vision and machine learning methods are used to detect the dangerous driving events. Inertial sensor data of the smartphone is also used to detect dangerous events by classifying car condition.

Surveillance videos from a vehicle-mounted camera are analyzed to make personal driving diary [5]. Atomic sub-events are detected by vehicle and pedestrian recognition and tracking. Features of local 3-D XYT trajectories of the vehicles and the other objects are used for the events detection. A decision tree based activity recognizer is designed to detect driving events from the first-person view videos by analyzing the trajectories and spatio-temporal relationships. The constructed diary enables efficient searching and event-based browsing of video clips, which helps the users to retrieve videos of dangerous situations.

Traffic Light Recognition

We use traffic light recognition results as features to detect dangerous driving events. Recognizing traffic lights accurately is a hard and challenging work. Figure 1 shows an example of day time traffic light of Japan. Figure 2 shows image of day time traffic light of USA. Color and shape of traffic lights are different in different countries and areas. In Japan, most traffic lights are arranged in horizontal direction. Traffic lights in USA are mostly arranged in vertical direction. Size and brightness are also different. Traffic lights of USA often has smaller size, bigger brightness than that of Japan

Color and shape of traffic lights are also different in different time. Figure 3 shows image of night time traffic light in Japan. Color and shape are different from that of Figure 1, day time traffic light image. In night scene, because gain of the camera is increased, traffic light lighting area saturated to white color. Traffic light color extends to surrounding area, which makes the recognition more difficulty. Traffic light color is also different for different kinds of light source, such as LED light and incandescent lamp traffic lights.

Color and shape of traffic are also different in different frames. As shown in Figure 4, color and shape of red traffic light is different in different frame because phase and frequency of traffic light is not synchronized with that of vehicle camera. The traffic lights blink in the vehicle camera videos.

Complex background also makes traffic light recognition difficult. In day time, objects such as color sign boards and billboards, which has same color as traffic lights, make false positive detection easily. In night time, neon lights and tail lamps of vehicles also make false positive recognition happen easily.

To solve problems mentioned above, many traffic light recognition methods are proposed. Color features are used for traffic lights recognition [6] – [16]. Selecting color space is important to get good recognition results. Circle feature is used to recognize traffic light [6]-[8]. Ellipse feature is also detected by genetic approach for traffic light recognition [9]. Object tracking is used to reduce false positive [10], [11]. Radial symmetry transform is used to recognize traffic light [14]. Multiple exposure is used to input image for recognizing easily [15]. Night time traffic light is recognized by color and shape recognition [16]. Spot shape feature is used to recognize traffic light [17], [18]. Because spot feature is similar to spot light and other small objects, it is easy to get false positive recognition results.

Circle, ellipse, spot and radial symmetry features are useful for traffic light recognitions. But because these features are very simple, day time complex background and night time lighting objects will cause false positive recognition easily.

Recognizing whole shape of traffic lights by machine learning method can increase recognition accuracy. But shape and color of the traffic light change a lot in different situation. In night time scene of Figure 4, there is only extended traffic light color area, without any whole shape can be seen.

Proposed Method

We propose a new method to detect dangerous driving events automatically from the surveillance video. Events such as rocket start, red light ignored dangerous driving can be detected. In our method, traffic light recognition is made at first. Then speed and acceleration data of car, traffic light recognition results are used as features to detect dangerous driving events. Motion information of speed and acceleration is used to detect the events, which is recorded by driving recorder or obtained by sensors in real-time.

Figure 1. Day time traffic light of Japan.

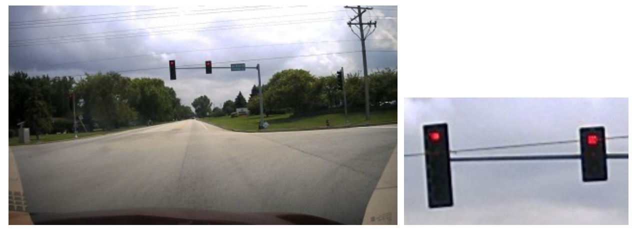


Figure 2. Day time traffic light of USA.

Figure 3. Night time traffic light of Japan.

Figure 4. Day time traffic light of Japan of different frames.

Color, shape and context features are used to recognize traffic light more accurately.

Vehicle road tests in both USA and Japan were made to demonstrate effectiveness of our proposed method. Real-time processing recognition experiments were made by vehicle camera video stream. Surveillance videos taken by driving recorder camera were also used to do traffic light recognition and dangerous driving events detection experiments.

Traffic Light Recognition

In our method, traffic lights are recognized at first. Red and green traffic lights recognition results are used to detect dangerous driving events. Color of traffic light is recognized by using dictionary parameters learned from traffic light image samples. *(Y, U, V*) color space features are used for color recognition. Then candidate area for shape recognition is calculated from traffic light image pixels recognized by color. Shape recognition is made using circle feature of the traffic light. Context features around traffic light area are used to reduce false positive recognition. Day time and night time scenes are recognized automatically from the image by SVM (Support Vector Machine) machine learning method.

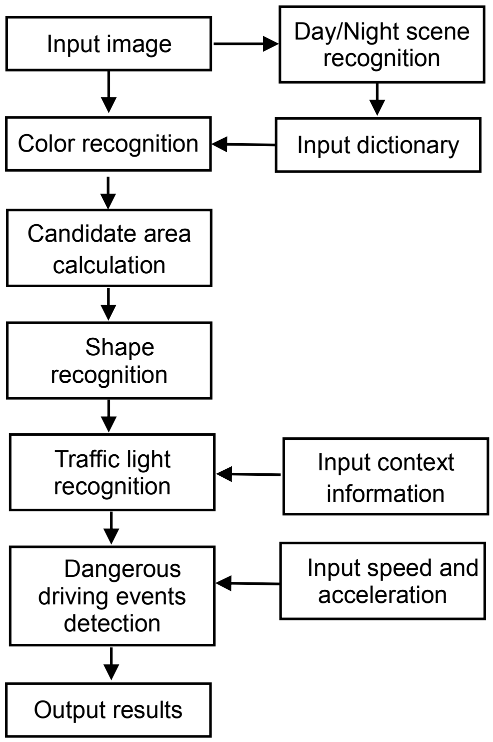


Figure 5. Flow chart of proposed traffic lights recognition and dangerous driving events detection.

Traffic light recognition dictionary is selected and parameters are set for day time or night time separately. Flow chart of proposed method is shown in Figure 5.

Color Recognition

Color space of (Y, U, V) is used to detect color of traffic light in our method. Color space of (R, G, B) is transformed to (Y, U, V) color space by Equation 1.

$$\begin{bmatrix} Y \\ U \\ V \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.147 & -0.289 & 0.436 \\ 0.615 & -0.515 & 0.100 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix} \quad (1)$$

Image samples of traffic lights are collected to learn recognition dictionary parameter. Pixels of lighting area are picked up and collected from traffic light images. As shown in Figure 6 (a), which illustrates Japan day time red traffic light. Lighting area of the traffic light is the red circle area. Figure 7 illustrates Japan night time red traffic light. Lighting area are saturated and traffic light color are extended to area around the lighting area. Pixels of color extended areas are picked up and collected from night time traffic light image samples for learning recognition dictionary parameters. Collected pixels of lighting area from learning sample images are transformed to (Y, U, V) color space for learning dictionary parameters.

Traffic light image samples are separated to groups, such as Japan day time, Japan night time, USA day time and USA night time groups. For each group, dictionary parameters are learned separately.

$$Y_{min} < Y < Y_{max} \quad (2)$$

$$U_{min} < U < U_{max} \quad (3)$$

$$V_{min} < V < V_{max} \quad (4)$$

For each sample image group, dictionary parameters are learned from traffic light lighting area pixels. From distribution of the traffic light lighting area pixels, dictionary parameters of Equation (2) – (4) are obtained which are minimum and maximum value in (Y, U, V) space. Traffic light color area is recognized by using the dictionary parameters. Figure 6 (b) illustrates recognition results of red color traffic light area pixels. Because of saturation and noise, detected color area is smaller than traffic light lighting area. Figure 7 (a) illustrates night time red traffic light and (b) is recognized color extended area.

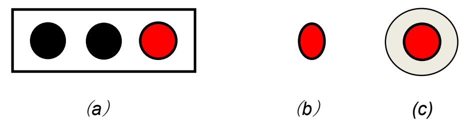


Figure 6. Color recognition results of day time traffic light color area. (a)Red traffic light; (b) Recognized lighting color area pixels; (c) Candidate recognition area

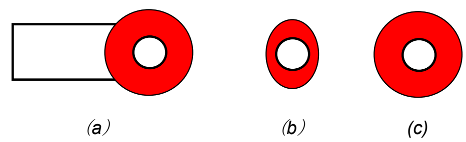


Figure 7. Color recognition results of night time traffic light color area. (a)Red traffic light; (b) Recognized color area pixels; (c) Candidate recognition area.

Making Candidate Area

As shown in Figure 6 (b) and Figure 7 (b), recognized traffic light color area is difficult for traffic light shape recognition. We make candidate area for shape recognition from the recognized color areas.

Expansion is used to make the candidate area. 1 pixel of recognized color area is expanded to N x N pixels image. Figure 6 (c) and Figure 7 (c) illustrate expanded images areas, by which shapes of the traffic lights can be recognized easily. Figure 6 (c) shows expanded red traffic light candidate area of day time. Figure 7 (c) shows expanded red traffic light candidate area of night time.

Traffic Light Shape Recognition

Shape recognition of traffic light is made in candidate area of Figure 6 (c) and Figure 7 (c). Circle features of the traffic light are used for recognition. We use Hough Transform to extract circle feature. The circle is expressed by Equation (5). Parameters of a and b are center axis of the circle and r is radius of the circle.

$$(x-a)^2 + (y-b)^2 = r^2 \quad (5)$$

By Hough Transform, parameter of (a, b, r) can be obtained, by which recognized results can be outputted by a rect. Figure 8 (a) shows circle recognition results by Hough Transform, which is Japan day time red traffic light. Figure 8 (b) is recognized result of the red traffic light, which is surrounded by a rectangle. Figure 9 (a) shows circle recognition result of Japan night time traffic and Figure 9 (b) is recognized result of the red traffic light of night scene.

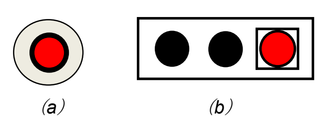


Figure 8. Shape recognition results of traffic light of day time. (a)Hough transform circle recognition result (b) traffic light recognition result.

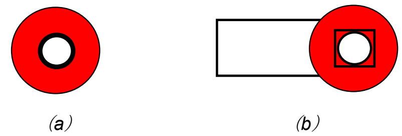


Figure 9. Shape recognition results of traffic light of night time. (a)Hough transform circle recognition result; (b) traffic light recognition result.

Context Information for Reducing False Positive

In day time scene, because of complex background, false positive detection happens easily. Color sign boards and billboards are easily recognized as traffic light. In night scene, tail lamps of vehicle and street lights are easily recognized as traffic lights. To reduce false detection, we use context information. Area of traffic light is used as feature to reduce false detection. Context intensity patterns are also used to reduce false detection.

Area of Traffic Light

Area of traffic light is used as feature to delete false positive. Area size of traffic light lighting area has a limited range. When the vehicle is near the traffic, traffic light area size has maximum value. If the vehicle is far from the traffic light, area size has minimum value. Area feature parameters are learned from traffic light image samples. Candidate area of Figure 6 (c) and Figure 7 (c) are used to get area feature parameters. Area size minimum value *Amin* and maximum value *Amax* are learned from traffic light image samples. If *A*, area size of a candidate traffic light, does not satisfy Equation (6), it is a false positive detection.

$$Amin < A < Amax \qquad (6)$$

For different times and places, different area feature parameters are learned. Day time, night time, USA and Japan scene use different area feature parameters. For each scene, image samples of traffic light are collected to learn the area feature parameters.

Context Intensity Pattern

Context intensity pattern around the traffic light area is used to delete false detection in our method. As shown in Figure 6 (a) and Figure 7(a), intensity patterns around traffic light area are used as context features to delete false detection. The context intensity pattern features around the traffic light area are average intensity values of rectangle blocks at specific position. Number, size, and positions of the rectangle blocks are learned from traffic light image samples. If a candidate traffic light has a context feature pattern matching that of traffic light, it is a traffic light. Otherwise it is a false positive detection. Context intensity pattern is different for time and place, such as day time and night, USA and Japan.

Day and Night Scene Recognition

Day time and night time scenes are recognized by input image. Average intensity of the input image is used as feature for recognition. The image is divided to blocks. N by N blocks are made. Number of dark blocks is used as recognition feature. Black block is defined by average intensity of the block. If average intensity is lower than a threshold value, the block is dark block. SVM (Support Vector Machine) is used to recognize day and night scene automatically. Recognition dictionary is learned by day time image and night images samples.

Dangerous Driving Events Detection

Dangerous driving events detection is made by using traffic light recognition results and speed and acceleration motion information. Rocket start and red light ignored dangerous driving events are detected.

Motion Information

As shown in Figure 4, because frequency of traffic light and camera sensor are not synchronized, traffic light area blinks at different frames. It is difficult to get motion information from traffic light tracking results. To solve this problem, we use motion information of speed and acceleration of the vehicle to detect dangerous driving events. Speed and acceleration data of the vehicle are obtained by sensor data recorded by driving recorder.

Rocket Start Detection

When traffic light changes from red to green, if a driver accelerate his car suddenly, it is a dangerous driving event, which is called rocket start. We use traffic light recognition results and motion information of vehicle's acceleration and speed to detect the event. When a red traffic light is recognized and then it changes to green, if acceleration becomes larger than a threshold value within a short period time, it is detected as rocket start dangerous driving events. Flow chart of rocket start event detection is shown in Figure 10. Rocket start level is defined by time between traffic light changes to green and acceleration value is increased bigger than a threshold value. Short time means strong level of rocked start.

Red Light Ignored Detection

When traffic light is red and a driver should stop his car according to traffic law, if the driver does not stop, it is a very dangerous driving event, which is called red light ignored. In our proposed method, the dangerous driving event is detect by red traffic light recognition and motion information of speed and acceleration of the car. If red traffic light is recognized and speed of the car is faster than a threshold value, it is the event candidate. Even the speed is not fast, if the acceleration is bigger than a

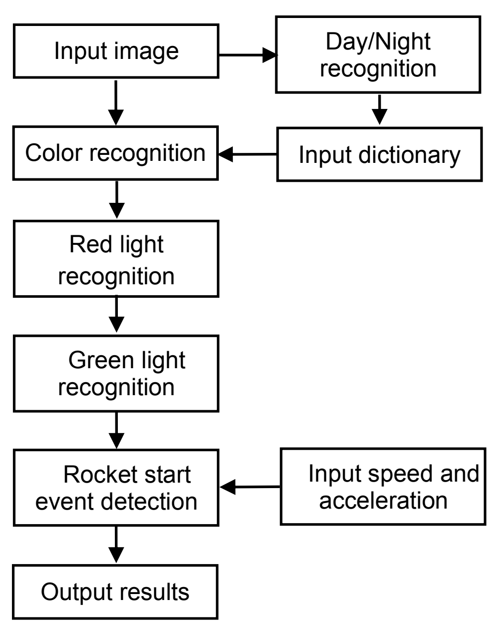


Figure 10. Flow chart of rocket start dangerous driving events detection.

threshold value, it is the event candidate too. If the car is far from the traffic light, it is not a dangerous driving event. It is an event candidate.

To delete false positive detection, size and position of the red traffic light in image frame are used features. If the car is far away from the red traffic light, it is not the dangerous driving event. Image samples are collected in which size and position of the red traffic lights are used to learn dictionary parameters. Candidate events are evaluated if it is false positive or not by the learned dictionary parameters. When the car is near the red traffic light, size of the traffic light becomes bigger and close to upper end of the image frame. False positive are deleted by dictionary parameters of size and position from upper end of image.

In Japan, there are green direction arrow traffic light as shown in Figure 12 (a), (b), (c). When the car turn right or left, if there is direction green arrow sign, it is not dangerous driving event. When red traffic light is recognized, we then detect the green arrow direction light. When red light and turn right green direction arrow light are detected, if the car go straightly it is recognized as dangerous driving event, as shown in Figure 13 (a). If forward direction green arrow traffic light is on, it is not dangerous event as shown in Figure 13 (b), (c). Flow chart of red traffic light ignored event detection is shown in Figure 11.

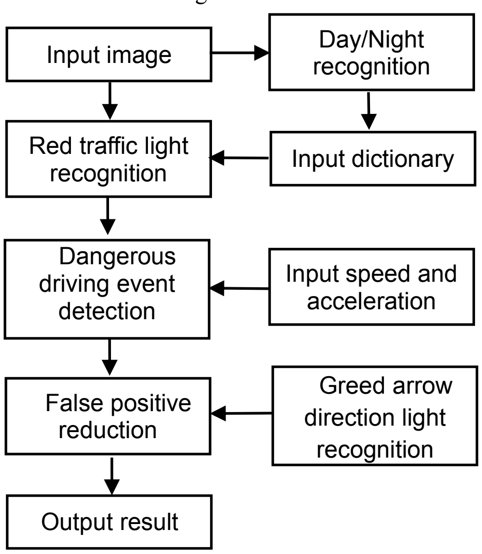
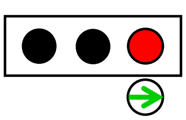
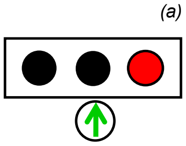


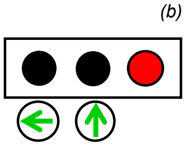
Figure 11. Flow chart of proposed red traffic lights ignored dangerous driving events detection.



(a)



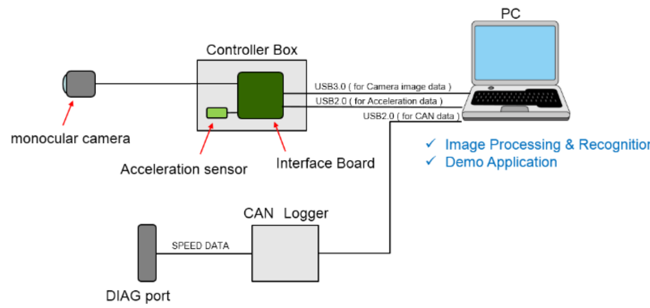
(b)



(c)

Figure 12. Red traffic light and green arrow direction traffic light. (a)Turn right; (b) Straight forward; (c) Turn left and straight forward.

(a)



(b)

Figure 13. Prototype for real-time traffic light dangerous driving events detection. (a)Vehicle camera; (b) Vehicle camera recognition prototype.

Experiment Results

Vehicle road testing experiments were made in both Japan and USA by a vehicle camera prototype. Vehicle camera and recognition prototype are illustrated in Figure 13. Figure 13 (a) is the experiment vehicle camera. Figure 13 (b) is the vehicle camera prototype. Video stream is inputted from the camera by a controller box. Image size is 1280x720 pixels. Frame rate is 30fps. Speed data was inputted from CAN data of car. Acceleration data was inputted by an acceleration sensor on the controller box. Traffic light recognition and dangerous diving events detection algorithm was running in the PC of the prototype.

Traffic light recognition algorithm is evaluated by the vehicle road testing experiments data, which is explained in next section.

Dangerous driving events detection are also tested in the vehicle road test. Because it is dangerous to make the events on purpose, we only made several dangerous driving of rocked start and red light ignored test. All of the dangerous driving events were detected properly.

We mainly evaluated our dangerous driving events detection algorithm by driving recorder video data.

Traffic Light Recognition Evaluation

Traffic light recognition is evaluated by data taken from Japan an USA vehicle road test. Part of image frames were used to learn recognition dictionary parameters. Japan day time and night time, USA day time data are used to learn recognition dictionary. In USA, only day time vehicle road test was made.

For Japan day time data, 60,365 images are used for evaluation. Recognition results example of Japan day time red traffic light is shown in Figure 14. Table 1 shows data of recognition results.

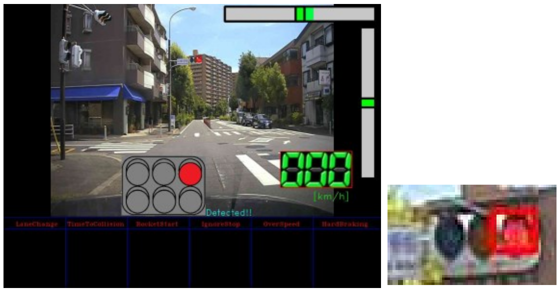


Figure 14. Recognition result example of Japan day time red traffic light.

Table 1 Testing results of day time Japan traffic light

Color	Red	Green
Recognition rate（%）	91.1	95.1
False positive rate（%）	0.04	0.04

For USA day time data, 45,815 images are used for testing. Recognition results example of green traffic light are shown in Figure 15. Table 2 shows data of the testing results.

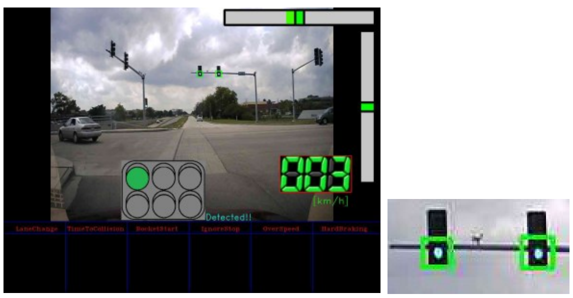


Figure 15. Recognition result example of USA day time red traffic light.

Table 2 Testing results of day time USA traffic light

Color	Red	Green
Recognition rate（%）	85.7	100
False positive rate（%）	0.0	0.06

For Japan night time data, 8,293 images are used for testing. Recognition results example of Japan night time green traffic light is shown in Figure 16. Table 3 shows data of testing results.

Figure 16. Recognition result example of Japan night time red traffic light.

Table 3 Testing results of night time Japan traffic light

Color	Red	Green
Recognition rate（%）	90.0	100
False positive rate（%）	0.64	0.02

Processing time test was made by PC environment of CPU:3.5GHz, momory:15.4GB, OS: Windows7. Processing time is list in Table 4. Real-time processing speed of 30fps was obtained.

Table 4 Processing time of traffic light recognition

Data	Japan day time	Japan night time	USA day time
Processing time(ms)	33.9	23.6	31.0

Figure 17. Driving recorder used in recognition experiment.

Dangerous Driving Events Detection Evaluation

As shown in Figure 17, driving recorder was used to take surveillance videos. The videos were used to test dangerous driving event detection. Camera of the driving recorder has 160 view angle. Image size is 1280x720. Frame rate is 30fps. Speed and acceleration data were recorded at same time by sensors of driving recorder.

We used 68 cars to collect surveillance video data, setting each car one driving recorder. Videos were recorded in SD card. The SD cards were collected every 3 weeks. Once the SD cards are collected, the surveillance video data were processed to find dangerous driving events. We collected SD cards 3 times. Because of large video data, it takes several hours to process one SD card. Detected each dangerous driving events result were recorded by a short video, which can be checked later.

Because the surveillance video data is too long, it is difficulty to make ground truth and evaluation the dangerous driving events recognition results. We randomly sampled the events detected results videos, evaluating the detection results. Rocked start dangerous driving events detection rate was about 70%. Red light ignored events detection rate was about 50%. Because dangerous driving events happened very seldom, number of the events were small. Red traffic light false positive recognition sometime caused false positive detection of the dangerous driving events, which decreased the recognition rate.

Rocket Start

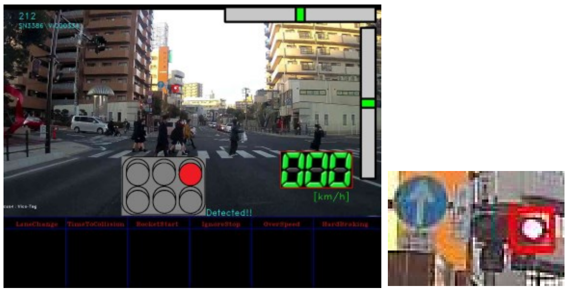
Experiment is made when traffic light color changes from red to green, if acceleration data increases to a value bigger than a threshold, it is rocket start. Rocket start level is defined in Table5. Rocket start level is defined by Rocked start time of Table 5. Rocket start dangerous driving events detection results example is shown in Figure 18.

Ignored Red Traffic Light

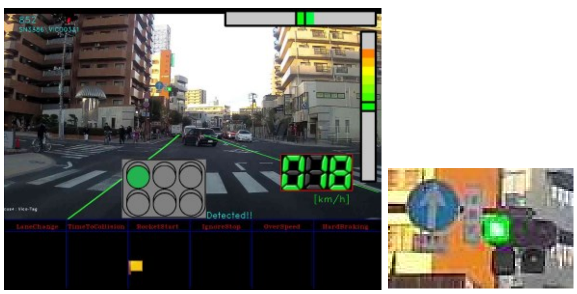
Ignored red traffic light dangerous events detection experiment is made by recorded vehicle camera surveillance video. Figure 19 shows example of the dangerous events recognition results. Traffic light is color and turn right green arrow traffic light is on, car speed is 52km/hour.

Table 5 Rocket start level

Rocket start level	Rocked start time(s)
1	1.0
2	2.0
3	3.0
4	4.0



(a)



(b)

Figure 18. Rocket start detection results example (a) Recognized red traffic light; (b) Rocket start when traffic light color changes from red to green and acceleration is bigger than threshold value.

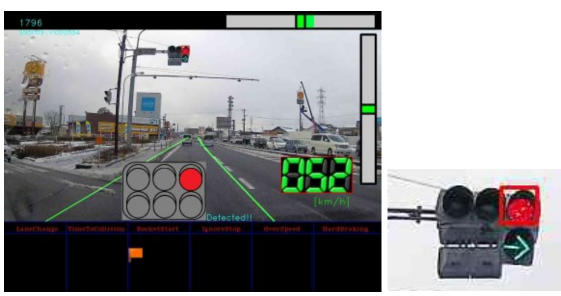


Figure 19. Red traffic light ignored dangerous driving event detection results.

Conclusion

We propose a new method to detect dangerous driving events automatically from surveillance video of vehicle camera. Events such as rocket start, red light ignored dangerous driving can be detected. In our method, traffic light recognition is made at first. Then speed and acceleration data of car, traffic light recognition results, multimodal features are used to detect dangerous driving events.

Color and shape of traffic lights are different in different countries and areas. Color and shape of traffic light image are also different at different shooting time, background and weather condition. It is difficult for conventional method to obtain both high recognition rate and low false positive rate. We proposed to use color, shape and context features to recognize traffic light more accurately.

Vehicle road tests in both USA and Japan were made to demonstrate effectiveness of our proposed method. Real-time processing recognition experiments were made in a car by vehicle camera video stream. Surveillance videos taken by driving recorder camera were also used to do traffic light recognition and dangerous driving events detection experiments. Traffic light recognition rate of 93%, false positive detection rate of 0.1%, real-time processing time less than 30ms results were obtained by our method.

68 cars which were equipped with driving recorder were used to collect surveillance videos for dangerous driving events detection experiments. Dangerous driving events were detected and recorded as short video, which is easy to be inspected. Red traffic light false positive recognition sometimes causes dangerous driving events detection false positive detection, which decreases the events detection rate. Improvement of traffic light recognition rate is future work.

References

[1] M. V. Ly, S. Martin, M. M. Trivedi, "Driver Classification and Driving Style Recognition using Inertial Sensors", IEEE Intelligent Vehicles Symposium (IV), pp. 1040 – 1045, 2013

[2] A. Naito, C. Miyajima, T. Nishino, N. Kitaoka, K. Takeda, "Driver evaluation based on classification of rapid decelerating patterns", IEEE International conference on Vehicular Electronics and Safety (ICVES), pp.108-112, 2009

[3] D. A. Johnson, M. M. Trivedi, "Driving Style Recognition Using a Smartphone as a Sensor Platform", 14th International IEEE Conference on Intelligent Transportation Systems, pp. 1609-1615, 2011

[4] Chuang-Wen You, Nicholas D. Lane, Fanglin Chen, Rui Wang, Zhenyu Chen,Thomas J. Bao, Martha Montes-de-Oca, Yuting Cheng, Mu Lin, Lorenzo Torresani, Andrew T. Campbell, "CarSafe App: Alerting Drowsy and Distracted Drivers using Dual Cameras on Smartphones", Proceeding of the 11th annual international conference on Mobile systems, applications, and services pp. 13-26, 2013

[5] M.S. Ryooa, Sunglok Choib, Ji Hoon Joungc, Jae-Yeong Leeb, Wonpil Yub, "Personal Driving Diary: Automated Recognition of Driving Events from First-person Videos", Volume 117, Issue 10, October 2013, pp. 1299–1312

[6] M. Omachi, S. Omachi, "Traffic light detection with color and edge information". International conference on computer science and information technology. 2009, pp. 284-287

[7] M. Omachi, S. Omachi, "Detection of traffic light using structural information", 10th international conference on signal processing, 2010, pp. 809-893

[8] M. Diaz-Cabrera, P. Cerri, "Suspended traffic lights detection and distance estimation using color features", 15th International IEEE Conference on intelligent transportation system, 2012, pp. 1315- 1320

[9] C. Chiang, M. Ho, H. Liao, A. Pratama, and W.Syu, "Detecting and recognizing traffic lights by genetic approximate ellipse detection and spatial texture layouts", International journal of innovative computing, Information and Control, 7(12), 2011, pp. 6919- 6934

[10] M. Diaz-Cabrera, P. Cerri, and P. Medici, "Robust real-time traffic light detection and distance estimation using a single camera", Expert Systems with Applications, 2015, pp. 3911- 3923

[11] F. Lndner, U. Kressel, S. Kaelberer, "Robust recognition of traffic signals", IEEE Intelligent vehicles symposium, pp49 – 53, 2004

[12] Y. Shen, U. Ozguner, K. Redmill, J. Liu, "A Robust video based traffic light detection algorithm for intelligent vehicles", IEEE intelligent vehicles symposium, pp. 521-526, 2009

[13] C. Yu, C. Huang, Y. Lang, "Traffic light detection during day and night conditions by a camera", IEEE international conference on signal processing, pp.821-824, 2010

[14] S. Sooksatra, T. Kondo, "Red traffic light detection using fast radial symmetry transform", IEEE international conference on electrical engineering/electronics, computer, telecommunications and information technology, pp. 1-6, 2014

[15] H. Kim, Y. Shin, S. Kuk, J. H. Park, H. Jung, "Night-time traffic light detection based on SVM with geometric moment features", World Academy of Science, International Juounal of Computer, Electrical, Automation, Control and Information Engineering Vol. 7, No. 4, pp. 454-457, 2013

[16] C. Jang, C. Kim, D. Kim, M. Lee, M. Sunwoo, "Multiple exposure images based traffic light recognition", IEEE intelligent vehicles symposium, pp.1313-1318, 2014

[17] R. Charette, F. Nashiashibi, "Real time visual traffic lights recognition based on spot light detection and adaptive traffic lights templates, IEEE intelligent vehicles symposium, pp.358-363, 2009

[18] R. Charette, F. Nashashibi, "Traffic light recognition using image processing compared to learning processes", IEEE international conference on intelligent robots and systems, pp. 333-338, 2009

Author Biography

Haike Guan received his PhD in information processing from Tokyo Institute of Technology (1995). Since then he has worked in Ricoh Company LTD. and currently is a senior specialist researcher in Ricoh Institute of Information and Communication Technology. His work has focused on research and development in image processing, pattern recognition, computer vision, human activity recognition and related fields.

Ryosuke Kasahara received his MS from Graduate School of Engineering, Tohoku University (2004). Since then he has worked in Ricoh Company LTD. and currently is a senior specialist researcher in Ricoh Institute of Information and Communication Technology. His work has focused on research and development in image recognition, imaging system and machine learning and related fields.

Tomoaki Yano received his BS from Department of Electrical Engineering, College of Science and Engineering, Ritsumeikan University (1986). Since then he has worked in Ricoh Company LTD. and currently is a senior specialist researcher in Ricoh Institute of Information and Communication Technology. His work has focused on research and development in image processing and image recognition and related fields.