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ADAPTIVE CRUISE CONTROL OF VEHICLE WITH VISUAL FEEDBACK OF A WEBCAM

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Abstract

The proposed adaptive cruise control system of vehicle guidance is based on the visual feedback from the webcam mounted on the vehicle. The road lines are identified first with the help of image processing techniques based on Hugh transform. Following, the tracking system is also developed based on some simple control algorithms to make the vehicles running inside the drivable area with or without a car in front within a safety speed limit. The computing of these control algorithms can be operated at a control center which connects the vehicles via WiFi communication system or directly on the microprocessor built in the vehicles to exchange the image information and control commands. Furthermore, the control center can monitor all the vehicles in some certain area for further applications such as dynamically planning the routes for all the vehicles to avoid congestion. To simplify the experimental setup, the drivable area is confined to a superhighway with only cars allowed on the road. The experimental results are given to demonstrate the effectiveness of the proposed control system.

1. Introduction

Advanced Driver Assistance Systems (ADAS) are popular nowadays. There are three major categories of ADAS : 1. The vehicle dynamics stabilization, 2. Information, warning and control and 3. Automated and cooperative driving. [1, 2] In addition, many visual-based guidance control system for vehicle had developed to detect the dangerous area, obstacles and road lines in the literatures. [3, 4] One major detecting method is line detection which means the drivable area embraced by the road lines been identified. [5, 6, 7, 8] Nowadays, the

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wireless communication being widely applied, modern vehicles usually are equipped with the components of wireless communication such as webcams, mobile communication and WiFi system. [9, 10, 11] The proposed control scheme focuses only on the information, warning and control of the vehicle with only one webcam mounted on the front of the vehicle with capability of wireless communication.

Furthermore, for a long journey on the freeway, drivers easily fall asleep during their long-time driving because of the road are usually straight and smooth. The proposed vehicle adaptive cruise control system is developed based on the visual feedback images. When the images are transmitted back to the control center/microprocessor then the image processing program will first analyze those images and then identify both the road lines and the rear part of the car in front if any. After detecting the road lines the proposed control scheme algorithm will start to keep the vehicle running inside the road lines within a proper speed limit. On the other hand, if a car detected in front then the image of rear part of the front car will be used as the reference to control the vehicle to follow the front car within the drivable area and with a proper distance.

In the proposed control scheme, both Canny process and Hough transform are applied to identify the edges of the road lines and the rear part of the front car. Besides, those images can be displayed on the screen in the control center. To calculate the distances between vehicle and road lines or the distance between two cars easily, the webcam is mounted on the center of the vehicle with a certain height predesigned. By using a feedback control technique, the vehicle automatically modifies its yaw angle to navigate the vehicle on the trail in the drivable area with a proper speed. The proposed visual-based adaptive cruise control system provides some experimental results to validate the performance.

2. System Structure

The vehicle used in the experiments of the proposed system is illustrated in Figure 1. The vehicle is equipped with not only self-propelled ability but also the WiFi module to communicate with the control center. And, a webcam (DCS-9301) mounted on the center of the vehicle to acquire the images of the road in front of the vehicle. [12] The control board of the vehicle has a WiFi module (RN-131C), a BS2 microprocessor module and some electric circuit to provide the necessary signals for driving two DC motors attached to the wheels of the vehicle. The webcam is also equipped with a WiFi module to provide image information to the control center via wireless WiFi communication system. There are total two vehicles in the experiments to demonstrate both the remote control system and the individual microprocessor-based control system.

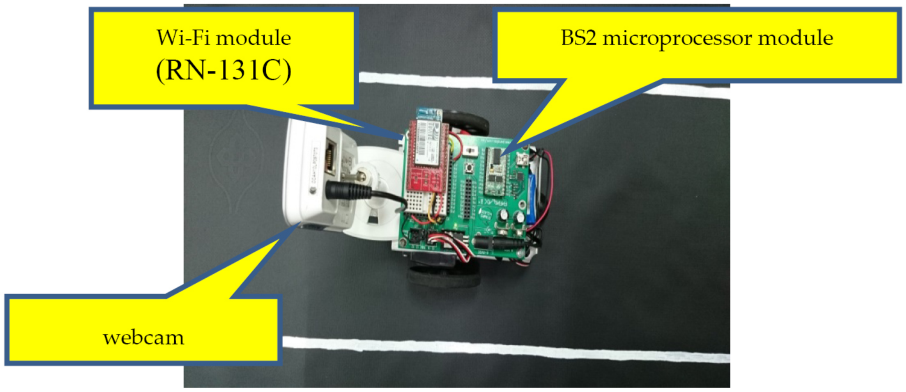


Figure 1. The proposed self-propelled vehicle.

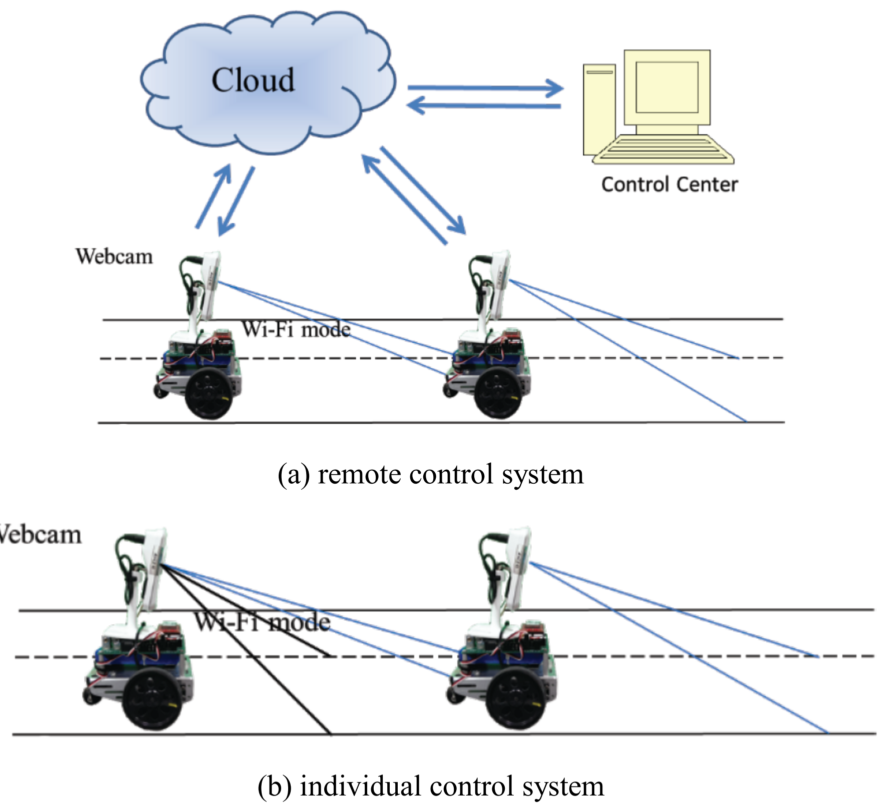
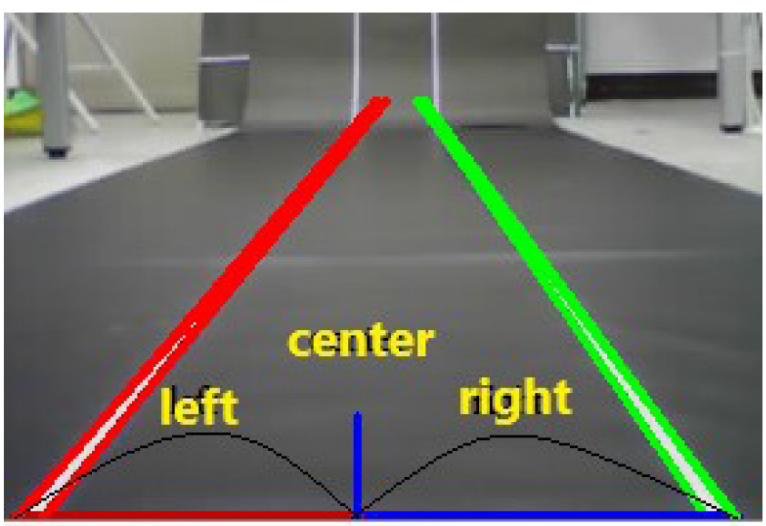


Figure 2. The sketch of overall system.

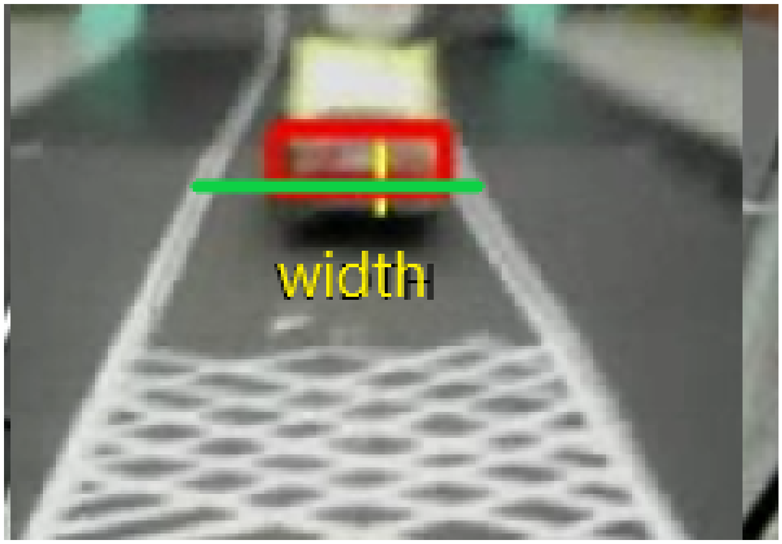
The sketch of the proposed systems is shown in Figure 2. In Figure 2(a), the overall system is composed of a control center and two vehicles equipped with a WiFi module and a webcam on each vehicle. They are connected via WLAN system, using the IEEE 802.11g protocol, in the proposed system. The webcams first sends back the image information to the control center via Internet as same as the control center sends the control signals to the WiFi modules on the vehicles to control the vehicles. On the other hand, the vehicle also can be control by the microprocessor built in the BS2 board as an individual control system shown in

Figure 2(b). However, the control center or the microprocessor will automatically release the control access back to the driver if the situation is needed or the communication connection is failed. In the proposed adaptive cruise control scheme, the driver always has the highest priority to control the vehicle than the control center or the microprocessor.

By using the image processing techniques, the road lines are first detected and displayed on the processed images based on transmitted image from the webcam as shown in Figure 3. In Figure 3(a), the microprocessor first filters out the useless information of the image sent back to the center as a global view of the control scheme. After the processes of binarization, Canny detection technique and Hough transform, the road lines are thus detected. [13] The program will then erase some useless lines with some criteria e.g. angles of the extended lines. The computer program also marks the center spot of the image as same as the center of the vehicle on the display. Then the distances between center to right line and left line are simultaneously calculated and shown on the images, too. During the running of the vehicle, the proposed control scheme maintains the equal distances of left and right within a safety range which lead the vehicle to stay inside the drivable area with a certain speed. This method is effective especially not only on the straight line but also on the curve line. However, the speed of the vehicle will be slow down within a multi-curves path because the transmission time delay is crucial in the rapid changing guidance. On the other hand, when a car is detected in front, the control program will keep the image of the rear part of the front vehicle within a certain size as a distance reference as shown in Figure 3(b). By extending the rear part of the front car to the edges of road lines, the distance between the controlled vehicle and the front car can be thus calculated. Of course, the speed limit is also considered. Once the front car is accelerated over a certain speed, the controlled vehicle will stop the tracking control process and only the guidance control process still work based on road lines detection only.



(a) display of road line detection



(b) display of rear part of front car (red) with road width

Figure 3. The display results of line detection by a webcam.

3. Guidance Control and Tracking Control

For explanation of different approaches, the control laws of the proposed control system are divided into three parts as follows:

3.1. Individual guidance control based on line detection

The control algorithm of the proposed individual guidance control law based on road lines detection is shown in Figure 4, the width of road and the size of the controlled vehicle are known previously. Such guidance control scheme is based on the road line detection with some basic control methodologies. The technique of road detection, guidance control scheme according to vanish point is also a popular approach. [14, 15] The line detection in the proposed control scheme is based on Hough transform and Canny process in the proposed control scheme with both road width and the size of controlled vehicle are known previously. The flowchart of the proposed guidance control scheme is also illustrated in Figure 5. The basic logic of the proposed guidance control is to remain the controlled vehicle inside the safety drivable area within a speed limit. The proposed control system will advise the driver if the speed is too slow or too high to keep it safe.

Navigation based on individual guidance control law

```
Start:
center = (frame. width /2);
Warning line = ((roadW-carW)/2)/2
If (rho < 0)
        right = pt2.x- center;
    else
        left = center -pt1.x;
End If

If((right > left) && (right - left)>Warning line)
        Turn Right
        else if ((left > right) && (left - right)>Warning line)
        Turn Left;
        else
        Go Straight;
End If
If (min. speed <= speed <= max. speed)
    Remain speed;
    else
  advise driver;
End If
Loop
```

Figure 4. The algorithm of guidance law based on line detection.

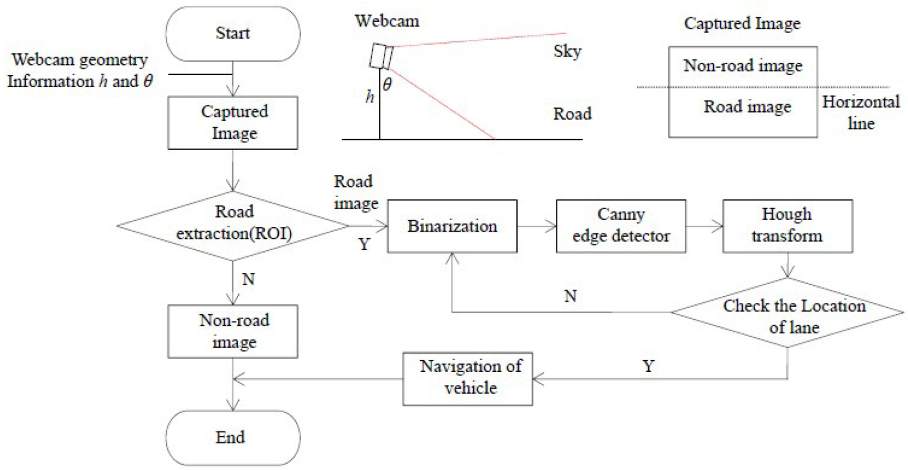


Figure 5. The flowchart of the road line detection.

3.2. Tracking control law

On the other hand, the algorithm and the flow chart of the proposed tracking control system are also illustrated in Figure 6 and Figure 7. The proposed tracking control algorithm keeps the controlled vehicle remaining a predesigned distance range within a speed range. The predesigned distance range usually be designed according to the speed of the controlled vehicle. The controlled vehicle will accelerate when the distance becomes larger same as the controlled vehicle will decrease its speed when the distance gets closer. The distance between two vehicles can be calculated by the image of the road width from the rear part of the front car. The maximum value of the road width of the road width with a safety distance is regulated to 120. The vehicle should be completely stops at the maximum value. With the road width of the image from the front car, the distance between two vehicles can be thus acquired by some simple triangular equation. The proposed tracking control scheme will alarm the driver when the speed is not inside a safety range. The proposed control system will hand over the control of the vehicle back to the driver if necessary. The tracking control must accompany with guidance control to ensure the controlled vehicle being inside the drivable area with a safety distance from the front car. In Figure 7, the rear part of the front car is captured to decide not only the distance between the front car and the controlled vehicle but also the category of the front car which can advise the driver to take precaution if needed.

Navigation based on the tracking system

```
Start:
If (trackroadwidth>=120)
        car stop
else
If (trackroadwidth>max.width)
speed--;
else if (trackroadwidth<min.width)
speed++;
else
remain speed;
Endif
End If
```

Figure 6. The algorithm of guidance law based on tracking system.

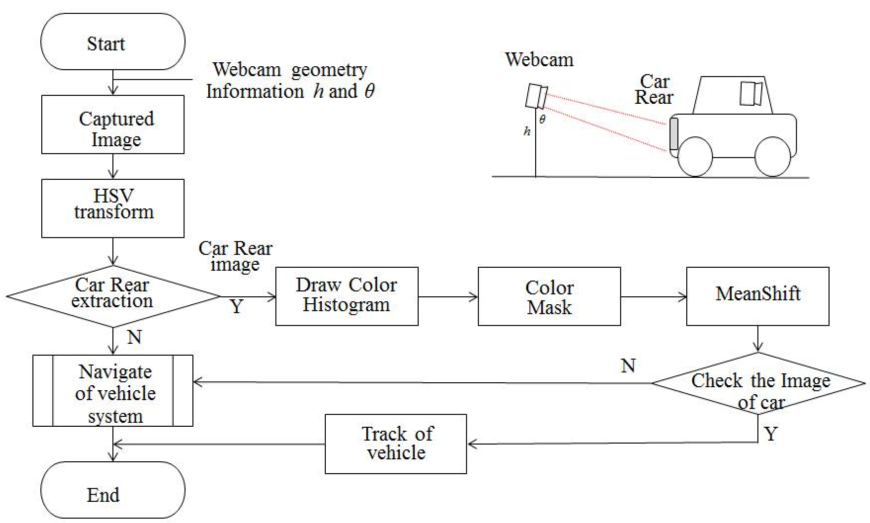


Figure 7. The flowchart of the proposed tracking system.

3.3. Remote control architecture

In the remote control architecture, the control process only activates if the communication between control center and the vehicle is successfully established as shown in Figure 8. Otherwise, the vehicle is controlled by the driver. The above mentioned algorithm includes the navigation laws, the remote control system is proposed to assure the successful guidance. Figure 5 and Figure 7 show the diagram of the feedback control of the controlled vehicle. The disturbance signal may be appeared which depends on the different conditions e.g. the car in next lane, sudden appearance of objects and so on. The reference is set to zero in the proposed system to guide the vehicle moving along the central line of the road. The algorithm in Figure 4 is also involved with the concept of the warning lines to compensate the transmission delay. On the other hand, the Figure 6 is also illustrated for the navigation law based on tracking system. The proposed control systems of the above mentioned algorithms are combined as a complete control scheme of adaptive cruise control system of the vehicles. Of course, the remote control scheme is also provided with the algorithm shown in Figure 8.

Actually, the concept of the warning line's design does not appear in the real image. The warning lines only designed in the program for guidance control of the vehicle to compensate the time delay caused by transmission as same as the distance in the tracking system.

Communication establishment of the remote control system

```
WiFi mode in Control Center (Client)
Start:
Set IP and Port
Connect link
If (connect ==true)
    receive image from server;
    Do
    navigation law;
    sendcontrol signal to server;
    Loop
End If

WiFi mode in Car (Server)
Start:
Waiting socket from Client
Receive IP and Port
Connect link
If (connect ==true)
Do
    receive control signal from client;
    send image to client;
Loop
End If
```

Figure 8. The algorithm of WiFi communication system.

This section may be divided by subheadings. It should provide a concise and precise description of the experimental results, their interpretation as well as the experimental conclusions that can bedrawn.

4. Experimental Results

The experimental setup comprises a notebook computer as the remote control center in the remote control architecture if needed, two self-propelled vehicles and a paper-made road as the driving road. Figure 9 demonstrates the physical scene of the experimental setup to conduct all the experiments of the proposed control system.

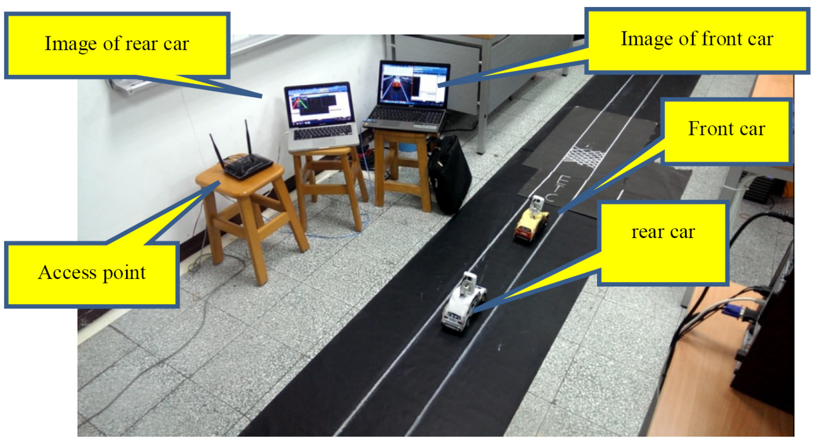


Figure 9. The experimental setup of the proposed system.

The experimental results are demonstrated based on the proposed visual-based vehicle adaptive cruise control system described as follows:

4.1. Guidance control based on road line detection

In Figure 10, the line detection image shows the experimental result of the guidance control law based on road line detection. The line detection is displayed on the image in red (left) and green (right) lines on the image of Figure 10. The blue line in the center indicates the center of the webcam mounted on the vehicle. The guidance control law gives the control signal to turn the controlled vehicle right due to the right is larger than left. Thus, the vehicle can go along the road with keeping the vehicle inside the road lines (drivable area).

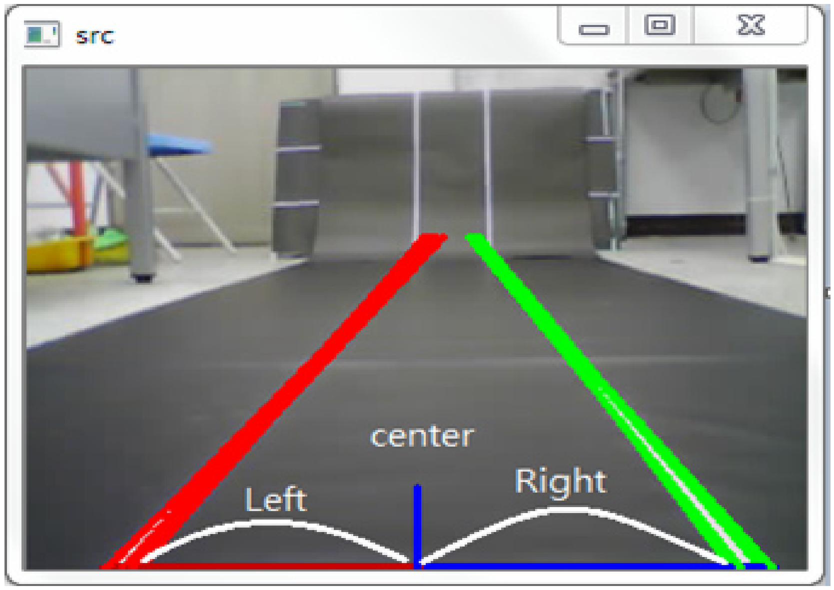


Figure 10. The experimental result with the images of the road lines and front car.

4.2. Guidance control based on tracking system

The Figure 11 shows the guidance control based on tracking control law. In Figure 11, the experimental result of tracking system is show on the image. The figure shows the image from the webcam of the rear car. The image includes not only the rear part of the front car in red rectangular but also the tracking center in yeloow to decide the controlled vehicle turning right to track the front car within a safety distance range. The track control law provides information of not only the distance but also the size of the front car.

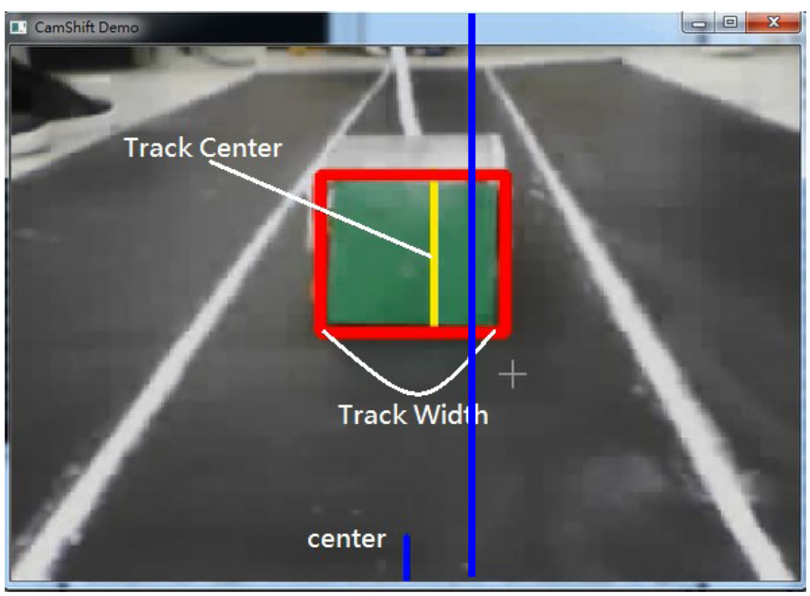


Figure 11. The experimental result with the images of the road lines and front car.

4.3. Adaptive cruise control system

In the adaptive cruise control, the line detection image in Figure 12 shows the experimental result of the guidance control based on road line detection. The line detection is displayed on the image in red and green lines on the upper part of Figure 10. The blue line, which shows in the line detection image, indicates the center of the vehicle and the moving direction. The guidance control law leads the vehicle go along the road and keep the vehicle inside the road lines (drivable area). As the guidance control based on tracking control law, the experimental result of tracking system is show in the image on the lower right part in Figure 12. The lower right part of the figure shows the image from the webcam of the rear car. The image of the rear part of the front car is marked in red rectangular to provide information of not only the distance but also the size of the front car. As same as the road lines in the guidance control previously mentioned, the combination of the above two control laws is a complete adaptive cruise control system to control the vehicle moving in a safety speed within the drivable area.

Besides, a remote control center is also provided to communicate with all the vehicles equipped with WiFi modules to acquire the information of all the vehicles. Under such circumstance, the remote control center thus can give the control signals to all vehicles for a better safety driving environment.

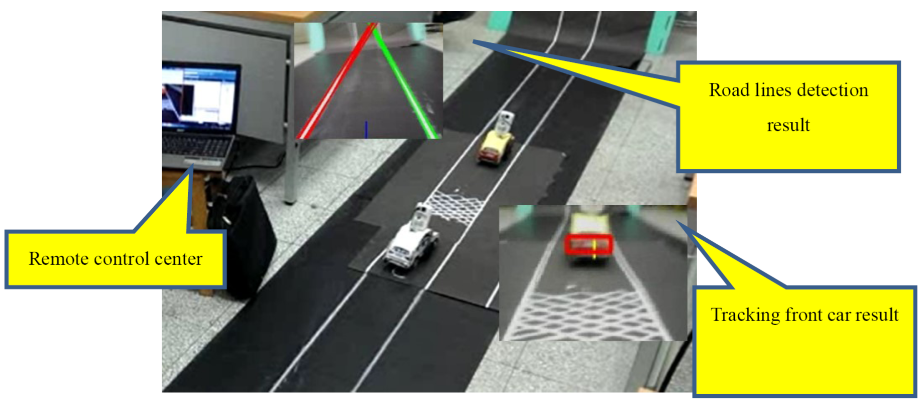


Figure 12. The experimental result with the images of the road lines and front car.

5. Conclusions

A visual-based vehicle adaptive cruise control system with only one webcam mounted on the vehicle has been developed in the proposed paper. First, the lines are detected after a series of image processing techniques then a tracking system based on the image of the front car is also designed to track the front car within a certain speed. Based on the knowledge from the webcam, the control laws of both line detection and tracking system are provided to control the vehicle. Besides, a remote control center is also provided to communicate with all the controlled vehicles equipped with WiFi modules. The experimental results show effectiveness of the proposed visual-based adaptive cruise control system. To summarize the proposed adaptive cruise system as following:

- Only one webcam is mounted on the vehicle.
- The guidance control law based on the image of line detection is provided.
- The tracking control law based on the image of rear part of the front car is provided.
- The remote control center is also provided to communicate with all the vehicles equipped with WiFi modules.

Besides, some extra applications can be developed on the knowledge from the proposed system such as deviation alert, adaptive brake assist and so on.

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