HUMAN-BASED GENERATION OF CONTROL PARAMETERS FOR VISUAL NAVIGATION IN AUTOMATIC VEHICLE GUIDANCE

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ABSTRACT

This paper describes a human-based generation method of control parameters required for visual navigation in automatic vehicle guidance. The authors have been carrying out experiments of visual navigation by using an actual vehicle since 1995. The most serious problem in experiments is that it is difficult to use public road for automatic vehicle guidance. The road traffic law in Japan where the authors are living is so severe that experiments on public road are not allowed. Thus, experiments by the authors are limited to those on university private roads. Therefore, the authors propose a generation method of control parameters that uses actual image of the public road. First, the actual control parameters such as steering angle and vehicle velocity were recorded together with sequence of forward images while a driver was driving on the public road. Then, the steering control parameters required for navigation were generated after analyzing the obtained images and these generated parameters were compared with the parameters obtained from actual driving on the public road. Modifications of the generation strategy were attempted many times so that the reproducing errors between generated parameter and actual parameter were reduced sufficiently. In this paper, how to generate the control parameters of which reproducing errors become small enough is described.

1. INTRODUCTION

Researches in autonomous driving vehicles were started from around 1985 and many control techniques for autonomous driving have been proposed [1]–[9]. The authors started on experiments of automatically navigated vehicles of outdoor use from 1995 [10, 11]. **Figure 1**, **2** and **3** show the latest vehicle designed and fabricated by the authors in 2001. This vehicle is navigated automatically by analysing information obtained from environmental sensors such as vision sensor, scanning laser range finder, long range ultrasonic sensor [12], etc. as shown in **Fig. 4**. In this vehicle, the vision sensor that consists of two pairs of stereo cameras plays

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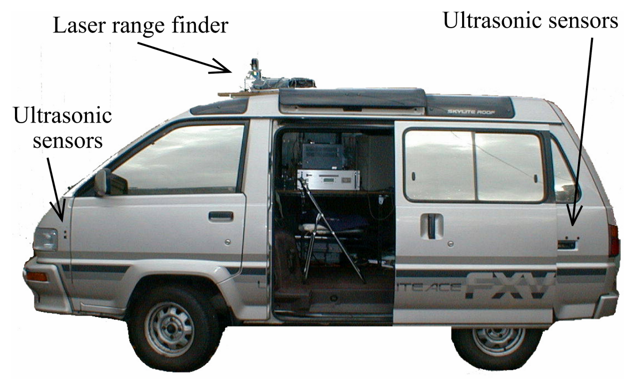


Fig. 1. External view of the latest vehicle.

the most important role in the vehicle navigation. Although we have to carry out many experiments in various environments to improve the reliability of navigation system, it is very difficult to perform the actual experiments on the public road because Japanese traffic law does not approve it. The actual experiments in automatic navigation are limited to a university private road only.

Because private roads in Tohoku University that are usable for the navigation experiments are narrow and short, enough experiments using actual vehicle could not be performed. Therefore, the authors started research works of automatic navigation based on computer simulation. This simulation-based approach has many advantages. First of all, it is free from danger because we do not need to drive any actual vehicle except when we record actual steering control parameters and we can try any method without the risk of traffic accidents. We do not need real-time processing of images either. This means that we can apply complex process that needs large computation power.

If we use complex algorithm to raise the reliability of image analysis, the processing time becomes longer and we cannot use it for real time control of actual vehicles. However, as computer technology is making a remarkable progress year by year, this long processing time will be sufficiently shorten in near future. This means that it is desirable to test the algorithm required for vehicle control in an-

Fig. 2. Power source for control system of the latest vehicle.

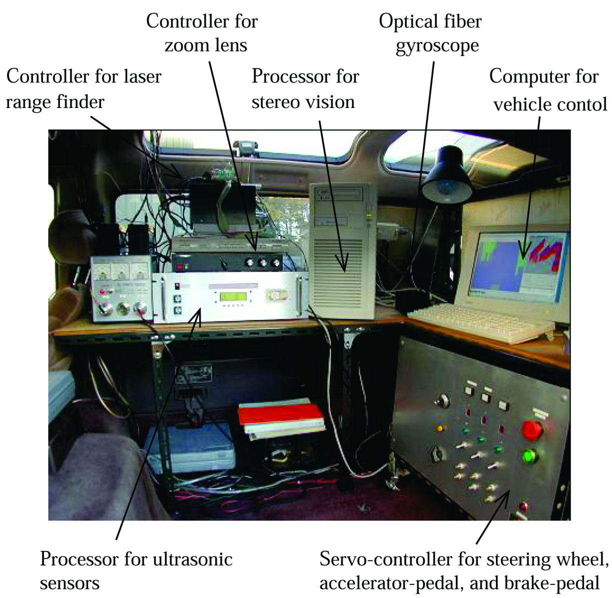


Fig. 3. Control system of the latest vehicle.

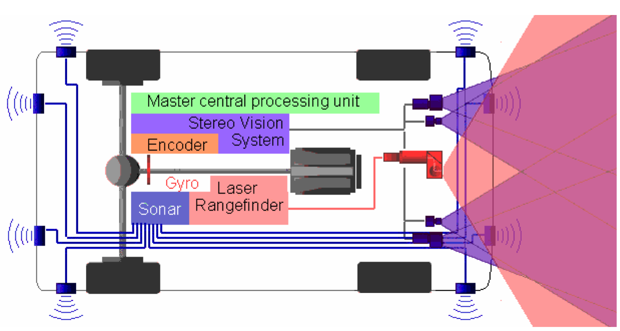


Fig. 4. Environmental sensors mounted on the vehicle.

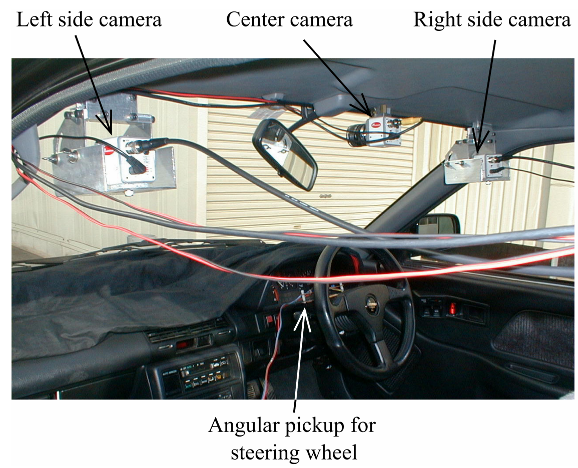


Fig. 5. Three CCD cameras for video capture and angular sensor for steering wheel.

ticipation of the rapid progress in computer technology even if it cannot be tested in real-time control for the present.

In this paper, the authors propose a method to generate operational commands such as steering wheel angle and vehicle velocity analyzing captured images in off line. The generation of operational commands is based on human experience. First, the database system was implemented. It learns how to operate a steering wheel related to scene of curved lane from operation of a human driver. The sets of profile of lane and angle of steering wheel are stored into database. When the system generates steering commands by itself, it recognizes lane and picks up database item that has a similar lane profile. The steering parameter is generated from those items. The proposed method can be applied to unknown, inexperienced roads. Most of previous learning-based vehicles [11, 13] became accustomed to a specific environment after learning.

Experiments were carried out. The scenery images of roads and operation data of a driver had been taken by using a car equipped with cameras and sensors. Our method learned driver's behavior and generated successfully almost the same operation as that of the human driver.

2. DATA RECORDING SYSTEM

The vehicle used for data capture is equipped with three CCD cameras, a magnetic encoder that detects rotary angle of steering wheel, a pulse type of vehicle velocity sensor, and other supporting apparatus as shown in **Fig. 5**. **Figure 6** shows a recording system of the steering parameters and images. In order to synchronize images and status of vehicle, they were combined into one video image by using a video quad switcher and a notebook PC as shown in **Fig. 7**. The notebook PC generates status-image from status of vehicle such as angle of steering wheel and vehicle velocity.

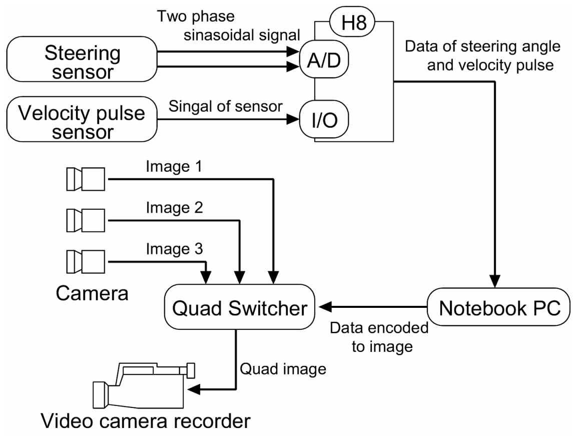


Fig. 6. Recording system of data captured by the actual vehicle.

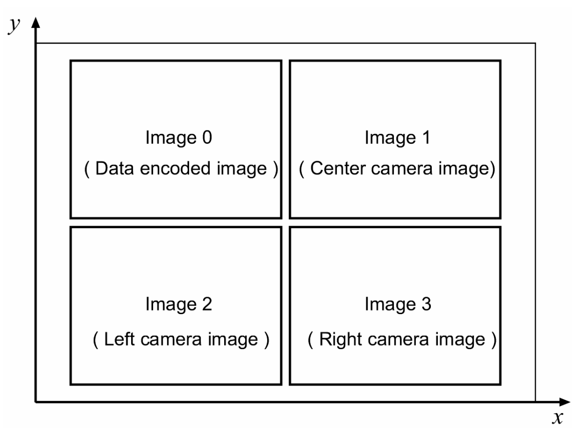


Fig. 7. Images to be combined.

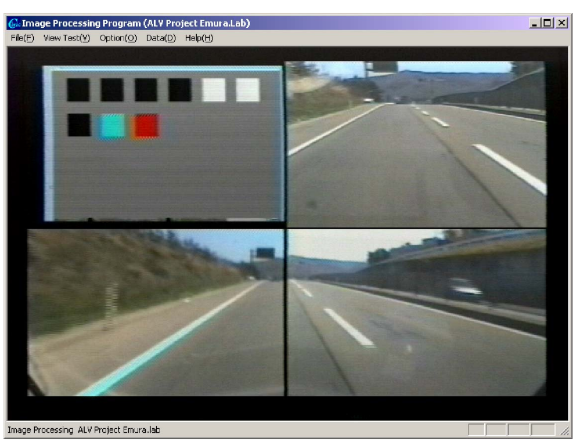


Fig. 8. An example of recorded image on public road.

These status values were encoded into sets of colored rectangles on the screen. The color of rectangle depends on value of each digit. The combined image was recorded with the VTR mounted on a compact video camera.

Figure 8 shows an example of images recorded by driving the vehicle on public road. The left upper image contains status of the vehicle. The right upper one, left lower one, and right lower one are road images captured with camera of center, left, and right, respectively. These video images are processed by the methods to be described in next chapter after capturing into PC.

3. IMAGE ANALYSIS AND GENERATION OF CONTROL PARAMETERS

A method of generating steering parameters based on a kind of learning is proposed in this chapter. First, traffic lanes are extracted from each of images. The profiles of these lanes are recorded into the database with the angle of steering wheel and the approximate velocity of vehicle when the system learns driver's behavior. The steering parameter is generated by picking up the most suitable one from the learned steering angles stored in the database.

3.1. Lane detection

The traffic lanes are extracted by binarizing image, labeling white area, and extracting feature. A threshold value is very important to binarize images if we want to get obvious segments. However, it deeply depends on weather, time, or traveling direction. This means the effective binarization needs self-determination of threshold. The authors used brightness of edge found on road image to decide threshold. First, edge area was detected by using Laplacian of Gaussian filter. Then, an average of brightness of pixels in edge area was calculated and used as threshold value. This operation successfully reduced effects of variation of lighting.

Each of all segments in the binarized image was listed by labeling and examined whether it was actual lane-dividing lines or not. We measured aspect ratio of each segment because those stripes had long and narrow shapes. The direction of segment was also examined to eliminate horizontal line such as stop line or zebra crossing. In addition, because some of those stripes would be parts of dashed line on the road, they could be assumed as one line when they had similar inclination and location.

Those lines were approximated to third-order spline curves in order to reduce data and to smooth them. The results detected in previous frames were used to improve approximation. There was close relation between previous image and current image because we used sequential images. This method that uses the relation with previous images is useful because most of road lanes in Japan are separated with

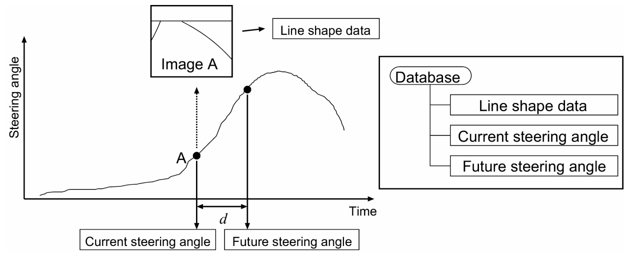


Fig. 9. Information that is registered into database.

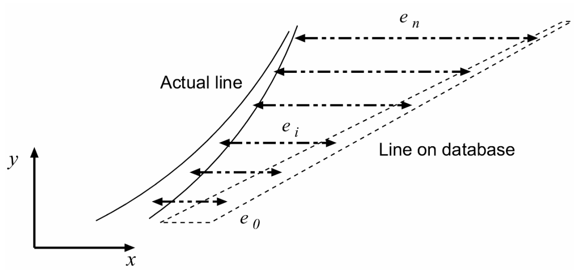


Fig. 10. Evaluation of similarity of lane profile.

dashed line and there are dead angles near the camera.

These approximated lines are used as lane profile hereafter. We did not apply inverse perspective transformation, and lane profiles on images were used directly.

3.2. Learning

The knowledge database was built in learning mode. In the database system, steering parameters such as steering wheel angle and vehicle velocity were memorized together with the shape of lane obtained from the above mentioned image analysis.

In the usual driving, drivers operate the steering wheel mainly according to the observed curvature of lane. Of course, we feedback tracking errors in driving, but we decide the angle of steering wheel by observing curvature based on our experience. The authors implemented this experience as database.

Each item in database consists of shape of lane and two values of steering angle as shown in **Fig. 9**. One of steering parameter is called current steering angle. It is literally actual angle of steering wheel recorded together with current image. The other one is called future steering angle recorded after some delay d of current scene. The future steering angle was introduced to take drivers' delay into consideration because the judge of drivers will appear on operation after a short delay. The delay time was set to about one second experimentally.

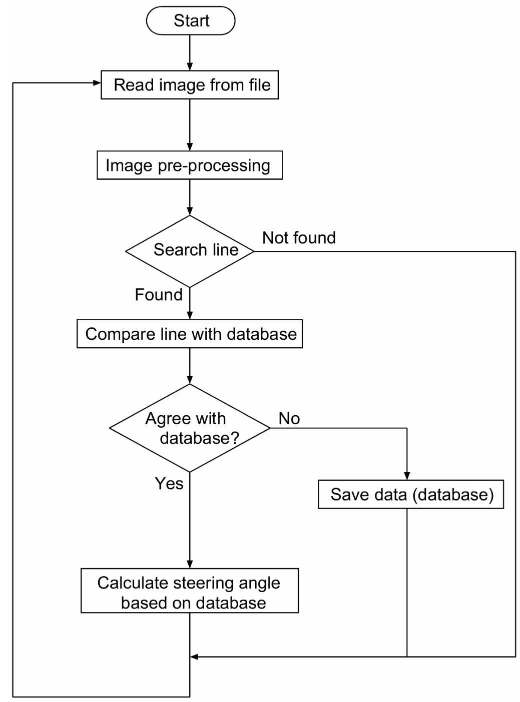


Fig. 11. Generation algorithm of steering parameters.

3.3. Generation of steering parameters

Steering parameters were generated with looking up the database. First, a road lane was extracted from image as mentioned above. The width of lane was compensated so that it coincided with that of database because lane widths of actual roads differ depending on regional environment and they had large effects on the evaluation of similarity described below.

Then, several candidates of items with similar lane profile were picked up from the database. The similarity between a lane obtained from current image and one obtained from database was evaluated as shown in **Fig. 10**. Distance e_i between the current lane and the lane on database at several points are measured and summed with weight. The differences between two lanes at distant points from camera, that are upward point on the image, were weighted highly because they decide the curvature of lane.

Finally, the steering parameter on current image was obtained by calculating a weighted mean of future steering angles of the candidates. Limitations were added to the time differential values of steering parameters in order to avoid rapid change caused by failure of image process, noises, and miss-learned database item. **Figure 11** shows generation algorithm of steering parameters.

Figure 12 shows an evaluation method of generated steering angle. In **Fig. 12**, trajectory A shows actual one and trajectory B shows generated one. D means the difference caused by steering error after a delay time. This delay

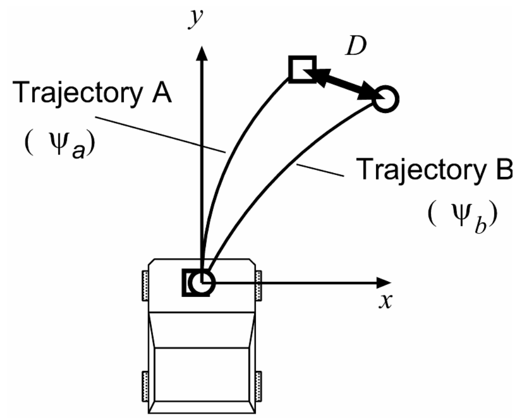


Fig. 12. Evaluation of generated parameters.

time was set to one second. Of course, if the vehicle speed is very fast, the delay time should be shorten. The suitableness of generated steering parameters was evaluated by distance D. Small D means that the error of generated parameters is small.

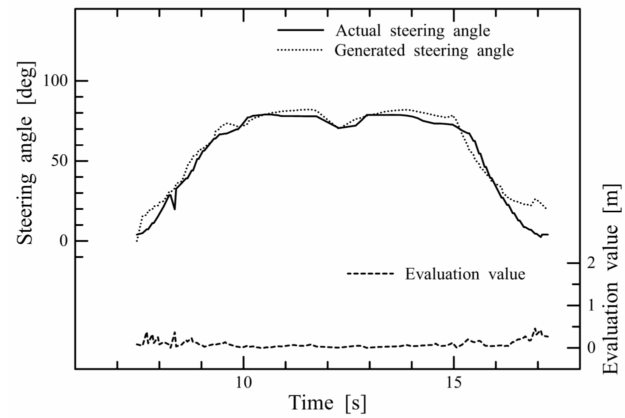
4. EXPERIMENTS

Experiments were carried out to confirm effectiveness of our method. The source video images were taken on public roads near our university including highways and urban ordinary roads. Those images were transferred into a PC that had dual PentiumIII processors. The processing software was built with multi-threading technique so that it could use two CPU's to speed up image processing.

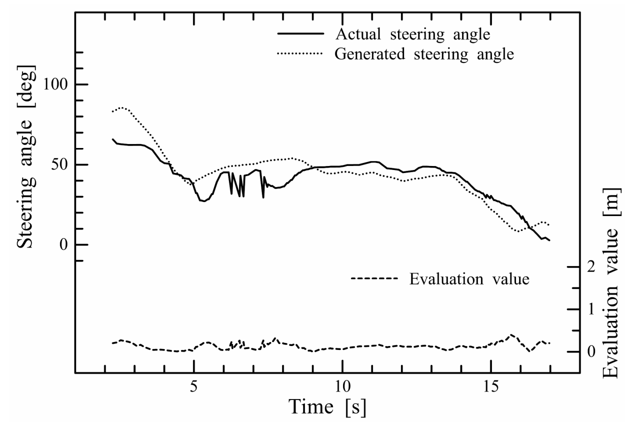
First, we performed the teaching process of the database referring to drivers' operation. We had 35 items on database after reducing redundancy. We call the image sequence used for learning "known course image" and call the image sequence which have not been used "unknown course image".

Figure 13(a) shows one of experimental results on known course images. The vehicle speed is about 40[km/h]. The figure contains angle of steering wheel of driver's operation (labelled as actual steering angle) and one generated with our method and database (labelled as generated steering angle). The horizontal axis describes the lapse of time. Evaluation value of the right vertical line shown in **Fig. 13** gives an index how generated steering parameters match to driver's operation, and this value is coincident with the difference D shown in **Fig. 12**. As mentioned in the previous chapter, D can be treated as an estimation error of curvature. The command value of visual feedback loop can be reduced if the evaluation value is small, that is, our generation method works well. As shown in **Fig. 13(a)**, it is obvious that the generated steering angle has enough accuracy on known course.

On the other hand, **Fig. 13(b)** shows one of results on unknown course images. The system had not experienced these images. Although the evaluation value became a little larger than results on known course, the generated steering angle matched with that of driver's operation sufficiently.



(a) Known course



(b) Unknown course

Fig. 13. Experimental results of generating steering parameters based on database.

We also implemented and carried out experiments on avoidance of on-street parking cars as shown in **Fig. 14**. **Figure 15** shows an example of experimental results of the generating steering parameters under object avoidance. Although a driver changed rapidly the angle of steering wheel to avoid the object, the evaluation value became small enough as shown in **Fig.15**. Thus, it is obvious that the obstacle was detected and steering parameters for avoiding them were generated successfully.

5. CONCLUSIONS

The authors proposed a method to generate steering parameter for automatic vehicle guidance by using human experience. This human-based method uses a database that learns behavior of a human driver by processing forward scene.

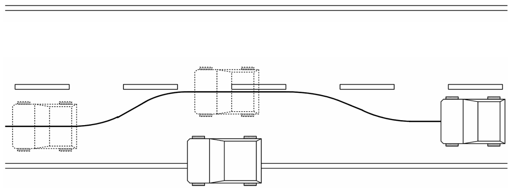


Fig. 14. Object avoidance.

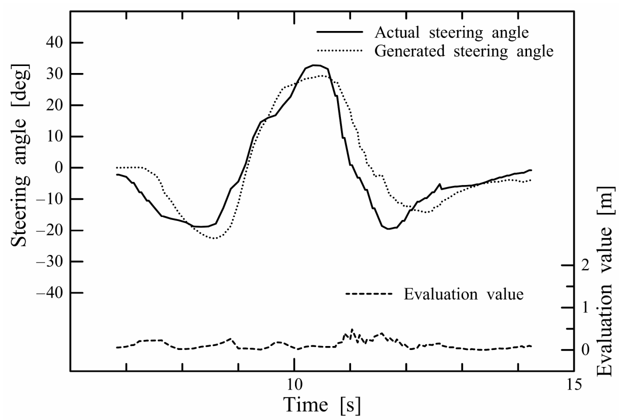


Fig. 15. An example of experimental results of generating steering parameters under object avoidance.

The database system learns how to operate steering wheel related to scene of curved lane from operation of the human driver, and the sets of profile of lane and angle of steering wheel are stored into database. Then, it recognizes lane and picks up database item that has similar lane profile. The steering parameter was generated from those items.

In order to build the database system, the authors designed and fabricated a vehicle equipped with three CCD cameras, angular pickup of steering wheel, vehicle velocity sensor, etc. The steering data were converted to sets of colored rectangles of on the screen. In order to synchronize captured images with steered information, they were combined into one video image by using video quad switcher, and the series of each combined image were recorded with the VTR.

First, the learning process was performed by using the database system. Next, the generation process was attempted. The proposed generation method was applied to unknown, inexperienced road. Experiments were carried out and algorithms for generating steering parameters were tested. The experiments showed good results, and our method generated steering parameters that were almost same as ones obtained from human driver. The generation in object avoidance was performed with good accuracy also.

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