High-Speed System and Robust Control in Highway

Ni Kai, He Kezhong

***Abstract*—Many systems have been created which can drive autonomously in structured road, but little work has been reported that describes the specific system solution in a high-speed(more than 120km/h) situation. So we concentrate on developing a high-speed system that performs well in the highway and other structured roads. THMR-V is such a high-speed system, which successfully achieved a maximal speed of 150km/h. In this paper, we will mainly discuss the system models and control algorithms implemented in our autonomous system.**

***Index Terms*—road model, lane detection, efficiency**

I. INTRODUCTION

Many systems have been created which can drive autonomously in structured road, such as RALPH, YARF, VaMoRs. The most important purpose of those autonomous systems is disentangling people from long-distance driving. A recent report[3] on the ConneXXion robot said: riders who could choose either the driverless vehicle or a conventional bus apparently picked whichever one arrived first. So besides the reliability, the high speed has become another necessary factor of real autonomous transportations.

In the past research works, many kinds of methods or system models have been raised to deal with the various road conditions. In most of these projects, the precision and reliability of the vision image process in complex environments is considered as the primary object, so most of these research works achieve this object at the cost of the vehicle speed. Although, there are several experiment systems have achieved a maximal speed more than 130km/h, but little effort has been made to guarantee the stability in high-speed situation.

So we concentrate on developing a high-speed system that performs well in highway and other structured roads. In the highway, the effect of the environment might be simplified to a great extent. Whereas, when the vehicle speed rises to 150km/h, there are more than forty meters passed between the two successive frames. So instantaneous response and robust control is the most urgent problem the high-speed system must handle.

The system we developed works perfectly in this situation. THMR-V can response quickly at a speed of 20ms/frame which is enough for take any necessary action. In the last six months we have had experiments for more than 200 hours in several roads in Beijing (e.g., BeiQing Road, JingChang Highway) and the percentage of the autonomous control is over 95%.

II. THMR-V: TSINGHUA MOBILE ROBOT V

THMR-V(Tsinghua Mobile Robot V) has its history up to 1986. National Key Lab of Intelligent Technology and System in Tsinghua University has done a lot of research work on mobile robot. THMR-III is the first outdoor intelligent mobile robot in China. After THMR-I, THMR-II, THMR-IIA，THMR-III, now we have its fifth generation: THMR-V (Fig. 1).

THMR-V is equipped with CCD camera, GPS, laser radar, magnetic compass, optical encoder, etc., and it consists of intelligent level, coordinate level and executive level. All the images are sampled by the camera on the top of the vehicle, and then VPS(Vision Process System, one of the modules of the executive level) processes the image sequences and generates the vehicle control commands, which is executed by the electric motors. The result of the vehicle status and command is sent to the coordinate level for further use (e.g., local path planning).

III. SYSTEM MODEL AND CONTROL ALGORITHM

A. Lane Tracking

There are many algorithms that might achieve the lane tracking. But as we referred ahead, the method must satisfy the requirement of fastness and robustness together.

Artificial neural network might adapt various kinds of roads after studying. But the process of adapting to a new road requires a relatively extended "retaining" period lasting at least several minutes, which is not acceptable in highway situation. Besides, the constant structure of the highway weaken the significance of this adaptation.

The "hypothesize and test" strategy used in RALPH in [1] has obviously the advantage of efficiency. However, if the amount of the templates is low(e.g., five templates), the results

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Fig. 1. THMR-V vehicle equipped with CCD camera, GPS, magnetic compass, and optical encoder.

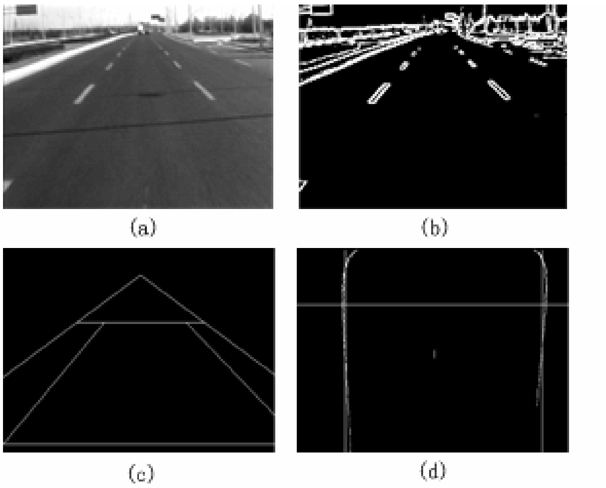

Fig. 2. (a).the origin road image. (b) the image after edge extraction. (c) the image of lane strips. (d) the image in the ground plane.

is not enough precise, only five possible curvatures, and can not supply enough information for following control procedure. Whereas if the amount is raised, the efficiency might be weakened.

After the image is perceived by the camera (Fig.2. (a)), the first procedure is the segment of the road edge. The Sobel operator is implemented as the primary method for edge extraction. What might influence the precision of this extraction is mainly mottled shadows and different sunlight conditions. So the system firstly samples the pixels at the bottom of the image to determine the average color of the road, and then classify the pixels to road and non-road when implementing the Sobel operator and make binary image. It successfully omits the edges of shadows as can be seen from Fig.2. (b).

Then we looked for the remaining edges from the bottom up. When it is for the first time, the full-range search will be taken; later, and the search range will reduce according to the previous result. When lane edges are not found for more than three frames, the research work will be reset.

A filter is implemented to delete the unexpected lines using the priori knowledge before getting the final result. Then we use straight lines fit to determine the equation of the two nearest lane strips, as shown in Fig.2.(C). The reason we do not use a Hough transformation is because of its high cost.

Then we project the current result from the image plane to the ground plane. In this procedure, we do not make strict camera calibrations to get the accurate remapping equations, but implemented a simple distortion to extend each row of the focused trapezoid to identical width. The result can be viewed in Fig.2.(d).

B. Road Model

There are many existed road model in previous autonomous systems. They might be classified into two types. One is the two parallel straight line models in SCARF[7], LANELOK[11], VaMoRs[9], some of those models are assumed to have a constant known width. The other is the curve models or successive segments models, which is applied in ARF[8], FMC[10].

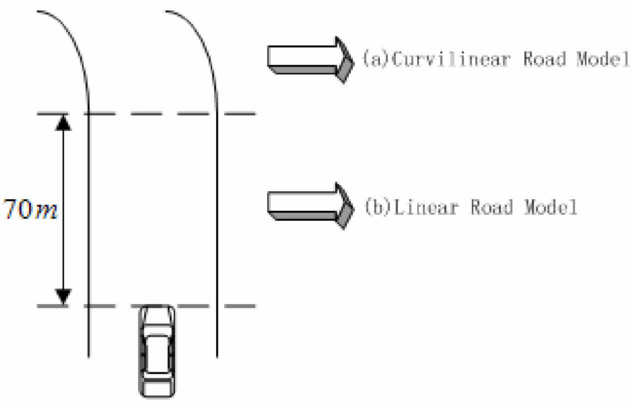

Fig. 3. The road model utilized by THMR-V. It consists of the curvilinear road model and the linear road

In our experiments, the first type models encounter many difficulties when road shape changes or sharp turns exist. It is too simple to describe the features of the road. The latter type models have enough information, but sometimes it makes the problem complex on the contrary. So we build a road model that costs little and supply enough features for the vehicle control.

The road model which is utilized by THMR-V consists of two parts. One is the curvilinear road model which is more than 70m far from the vehicle (Fig.3.(a)); the other is the linear road model which is 0-70m far from the vehicle (Fig.3.(b)). For the road can be approximately considered as straight lines in that distance.

The image sampled by camera is first processed by the curvilinear model to detect whether there is a sharp turn far ahead. The system calculates the percent P_{left} of the pixels fall

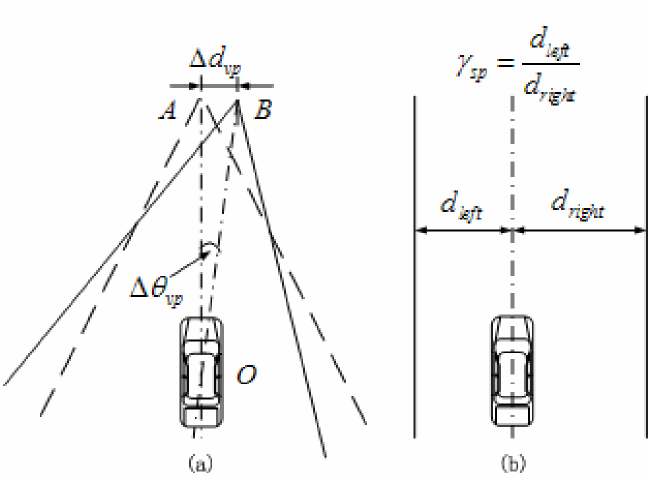

Fig. 4. The parameters we used in the vehicle control. (a).the deviation of the current vanish point. (b) the ratio of the distances from the vehicle to the left and right lane strips

on the left of the corresponding lines of the linear road model. If P_{left} is greater than 80% or lower than 20%, then it is considered that there is a sharp turn, and the curvilinear road model will bring the steering action forward; if there is no sharp turn ahead, then the linear road will take charge of adjusting the posture of the vehicle.

In the linear road, we use two parameters to describe the status of the vehicle. One is the distance between the origin vanish point to the current lane vanish point, which is depicted in Fig.4.(a). As we know, when the orientation of the camera is parallel to the lane strips, the two strips in the image plane intersects at the origin vanish point, which is at the horizontal center of the image; when the vehicle have rotated, the vanish point begin to leave the old position. The more the vehicle have rotated, the longer is the deviation of the vanish point, which satisfy the following criteria:

$$\frac{\Delta\theta_{vp}}{\Delta d_{vp}} = \frac{\Delta\theta_{vp}}{OB*\sin\Delta\theta_{vp}} \doteq \frac{\Delta\theta_{vp}}{OA*\sin\Delta\theta_{vp}} \doteq \frac{1}{OA} \tag{1}$$

when $\Delta\theta_{vp}$ is enough small. So the deviation of vanish point shows us the rotation angle of the vehicle.

The other is the ratio of the distances from the vehicle to the left and right lane strips, which is depicted in Fig.4.(b). It shows whether the vehicle need a big steering to avoid rolling the lines.

In most of the time, the system adjust the orientation according to the deviation Δd_{vp}, and the vehicle will just stay at the center of the lane. If unexpected factors influence the movement(e.g., the slant), the system will analyze Δd_{vp} and γ_{sp} together to make the planning.

C. Control Algorithm

Fig.5 illustrates the flow of the whole algorithm. The system firstly judge whether a sharp turn exists and makes the steering action if it dose so until P_{left} is between 0.2 and 0.8.

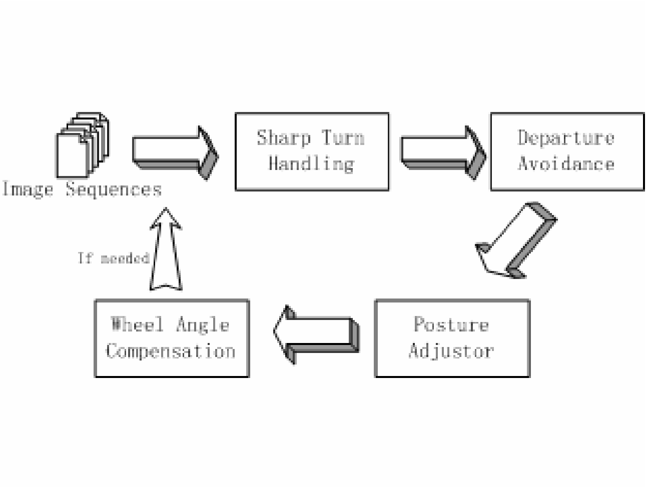

Fig. 5. The flow chart of THMR-V control algorithm.

Then the system will check whether there is risk of departure according the following inequality:

$$if \begin{cases} \gamma_{left} > 1.5 \\ 0.67 < \gamma_{left} < 1.5 \\ \gamma_{left} < 0.67 \end{cases}, then\ steer = \begin{cases} (\gamma_{left} - 1)^k \times steer_{\max^+} \\ 0 \\ (1 - \gamma_{left})^k \times steer_{\max^-} \end{cases} \tag{2}$$

where k represents the strength of the steering command, $steer_{\max^+}$ and $steer_{\max^-}$ is the maximal steering angle which is permitted. In our system, k is 0.9.

If the steer = 0, that is to say that the vehicle is at the center of the lane on the whole, then the system will adjust the vehicle orientation on the basis of Δd_{vp}:

$$steer = \Delta d_{vp} / k_{vp} \tag{3}$$

where k_{vp} adjusts the strength of the posture correction.

The overage of the steering command must be considered. When the system tries to rectify the deviation, the wheel must be deviated to the other side and so the vehicle can be recentered. That is to say, appropriate compensation should be applied if the steering commands satisfy the following condition; otherwise the vehicle might slide to the opposite side after going back to the center:

$$\text{if } |steer| > k_{over} \text{ and } C > C_{over}\text{, then } steer_{compensate} = \overline{steer_{over}} \tag{4}$$

where C is the count of successive frames that satisfy $|steer| > k_{over}$, k_{over} represents the threshold of the normal steering strength which need no compensation, C_{over} represents the threshold of the steering count, and $\overline{steer_{over}}$ is the average of the steering that need compensation.

The flow chart of control algorithm might be seen in Fig.5.

IV. CONCLUSIONS

In the last six months, more than 70 experiments have been taken in some highways and structured roads. Our autonomous system successfully achieved a maximal speed of 150km/h and an average speed of more than 100km/h. It can adapt different highways, no matter the lane width and the lane strip type, and it also performed well under most of weather conditions and other natural environments.

The speed and stability make it is possible to be a reliable system in real transportations. CCTV(the national TV network of China) have recently made a program of our autonomous system – THMR-V.

V. FUTURE WORK

We are preparing a long-distance trip, from Beijing to Shanghai, across a sizable part of China. This might verify the stability and improve the performance of THMR-V significantly.

In current system, because of few intersections exist in highways, limited work has been done in intersection navigation, and its result need to be improved. We are also currently developing techniques which allow THMR-V overtakes intelligently. Existing path planning on the basis of map information and GPS is also considered to be integrated into highway vision navigation.

VI. ACKNOWLEDGMENT

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REFERENCES

[1] D. Pomerleau, “RALPH: rapidly adapting lateral position handler,” Intelligent Vehicles '95 Symposium., Proceedings of the , 25-26 Sep 1995 Page(s): 506 -511

[2] Bertozzi M., Broggi A., “GOLD a parallel real-time stereo vision system for generic obstacle and lane detection”, Image Processing, IEEE Transactions on , Volume: 7 Issue: 1 , Jan 1998 Page(s): 62 -81

[3] K. Kluge, C. Thorpe, “Explicit models for robot road following,” Robotics and Automation, 1989. Proceedings., 1989 IEEE International Conference on , 14-19 May 1989 Page(s): 1148 -1154 vol.2

[4] Chuck Thorpe, Olivier Clatz, Dave Duggins, Jay Gowdy, Rob MacLachlan, J. Ryan Miller, Christoph Mertz, Mel Siegel, Chieh-Chih Wang, Teruko Yata, “Dependable Perception for Robots”, 2001

[5] E.D.Dickmanns, R.Behringer, D.Dickmanns, T.Hildebrandt,M.Maurer, F.Thomanek, J.Schiehlen, “The seeing passenger car `VaMoRs-P',” Intelligent Vehicles '94 Symposium, Proceedings of the , 24-26 Oct 1994 Page(s): 68 -73

[6] Didier Aubert, Karl Kluge and Chuck Thrope, “Autonomous Navigation of Structured City Roads,” Proceedings of SPIE Mobile Robot V, 1990

[7] Crisman J.D.,Thorpe C.E.,” SCARF : a color vision system that tracks roads and intersections,” Robotics and Automation, IEEE Transactions on , Volume: 9 Issue: 1 , Feb 1993 Page(s): 49 -58

[8] D. M. McKeown, J. L. Denlinger, “Cooperative Methods for Road Tracking in Aerial Imagery,” *Proceedings of IEEE Conference on Computer Vision and Pattern Recognition*, Ann Arbor, Michigan, June 1988, pages 662-672

[9] Mysliwetz, Birger D. and Dickmanns, E. D., “Distributed Scene Analysis for Autonomous Road Vehicle Guidance,” In Proceedings SPIE Conference on Mobile Robots, November 1987

[10] Kuan, Darwin, Phipps, Gary, Hsueh, A-Chuan, “Autonomous Land Vehicle Road Following”, In Proceedings First International Conference on Computer Vision, June, 1987

[11] S.K.Kenue, “LANELOK: Detection of lane boundaries and vehicle tracking using image-processing techniques, Parts I and II”, SPIE Mobile Robots IV,1989