International Journal of Automotive Technology, Vol. 3, No. 2, pp. 71−77 (2002)

1229−9138/2002/008−05

LATERAL CONTROL OF AUTONOMOUS VEHICLE USING LEVENBERG-MARQUARDT NEURAL NETWORK ALGORITHM

K. B. Lee[1)], Y. J. Kim[1)], O. S. Ahn[1)] and Y. B. Kim[2)*]

[1)]Graduate Students, Chonnam National University, Department of Mechanical Engineering, Kwangju 500-757, Korea
[2)]Associate Professor, Chonnam National University, Department of Mechanical Engineering, Kwangju 500-757, Korea

(Received 11 June 2002; Revised 19 February 2002)

ABSTRACT−A new control method for vision-based autonomous vehicle is proposed to determine navigation direction by analyzing lane information from a camera and to navigate a vehicle. In this paper, characteristic featured data points are extracted from lane images using a lane recognition algorithm. Then the vehicle is controlled using new Levenberg-Marquardt neural network algorithm. To verify the usefulness of the algorithm, another algorithm, which utilizes the geometric relation of a camera and vehicle, is introduced. The second one involves transformation from an image coordinate to a vehicle coordinate, then steering is determined from Ackermann angle. The steering scheme using Ackermann angle is heavily depends on the correct geometric data of a vehicle and a camera. Meanwhile, the proposed neural network algorithm does not need geometric relations and it depends on the driving style of human driver. The proposed method is superior than other referenced neural network algorithms such as conjugate gradient method or gradient decent one in autonomous lateral control.

KEY WORDS : Back-propagation algorithm, Levenberg-marquardt algorithm, Sobel method, Autonomous vehicle, Lateral control, Vision system, Ackermann angle

1. INTRODUCTION

The recent vehicle technology trends are toward to obtain improving the comfortness and intelligence of the vehicle. Among the recent trends, lots of researches are directed to the vehicle automation, *i.e.*, autonomous vehicle or pseudo-unmanned vehicle operation. Autonomous vehicle not only provides more convenient transportation, but also it could protect human lives from traffic accidents caused by human lack or unawareness. Vision based autonomous vehicle is widely studied because it can provide lots of traffic information and it does not need extra facilities to the existing roads (Passino, 1995; Manigel *et al*. 1992; Tsugawa, 1994; Yang *et al*., 1996).

Kuan (1988) has developed general lane tracking vision system. The general tracking system utilizes a camera image, and then road profile edges are extracted from the obtained image data. The road image information is obtained by transforming the image from camera coordinate into vehicle related coordinate. Also relevant procedures are involved to obtain final vehicle steering control command for lateral autonomous motion. Heavy computing overheads are necessary for coordinate transformation and control algorithm determination. In his methodology the most time-consuming overheads are (i) image parameter values calculation for the lane extraction (ii) vehicle parameter calculation for relevant vehicle lateral control. Therefore, general tracking method has its limitation for applying to real-time vehicle control.

To overcome these problems, Polerleau (1997) utilized ALVNN (Autonomous Land Vehicle in a Neural Network) method. An ALVNN network system has the characteristics of having one forward hidden layer. The image information from a camera is utilized as an input layer, and a steering vector information is decided as an output layer. The method has the advantage of following the expert driver patterns, however, it is based on the limited information because image data algorithm for extracting the vehicle drive lanes is not involved. Meanwhile, Ryoo *et al.* (1999) added vehicle driving lane image information to supplement these problems. Ryoo *et al.* utilized general neural network algorithms, however, their method has the disadvantage of having long simulation time to extract necessary driving information.

**Corresponding author.* e-mail: ybkim@chonnam.ac.kr

Their system has been applied to the form of mobile robot instead of a vehicular system.

The lateral vehicular control system with road profile information extraction is also another important research area for autonomous vehicle. Recently many researchers have introduced lots of control systems such as fuzzy control, neural network system, genetic algorithms. This paper utilizes Levenberg-Marquardt method, which is widely known as a fast perception algorithm, to construct neural network system for autonomous accurate lateral vehicular control (Kim, E-S, 1999). Also, real proto type vehicle having a steering system which has a tie rod, a knuckle, a steering rack and pinion and steering column has been built and tested. The proposed method in this paper is one of advanced neural network method based on skilled driver steering information. The neural network system comprises of multi-hidden layers and new back propagation algorithm using Levenberg-Marquardt method, and it is best suited for fast and accurate results. The usefulness of the proposed network system is compared with other method obtained geometric control algorithms using Ackermann steering angles in simulation. Also, the proposed method is applied to the real proto type vehicle to show the applicability to real autonomous lateral control.

2. ROAD LINE RECOGNITION ALGORITHM

The road image is fed back to the system computer from a camera, which is installed above the driver seat. Then, the real time image calculation algorithm is utilized by taking partial image for the sake of reducing calculation time. Although partial image is used for road profile extraction, it is possible to obtain enough information for accurate steering, and it is verified by experiments. Exact road lane extraction process is very difficult due to environmental effects such as light intensity variation, noise effects and line color variations. Therefore, we extract several digital points from lane image information to satisfy lateral vehicular control motion. Some feature points for lane recognition are enough to obtain vehicle lateral information in order to steer and control the vehicle to trace the lane effectively.

The first procedure to get the featured vehicle lane is to draw vertical line in the image, which is representative of one lane, and then three data points are obtained from that lane. Also other three data points are later obtained at the different vertical image lane, which is representative of right lane. In extracting six digital points, the horizontal position of the points are fixed and vertical position of the points are decided according to the lane gradient. Therefore, total 6 digital points are extracted from one image screen for simulating lateral vehicle motion. Full horizontal screen frame is not utilized for time sake, instead small horizontal searching area is primarily decided to obtain digital featured points. In doing so, calculation time can be reduced significantly and the possibility of recognition error due to lane recognition noise can be minimized as well. The utilized algorithm is relatively fast to obtain lateral steering road information, which can make real time vehicular lateral control motion possible. The detailed lane detection algorithm can be summarized as follows.

Step 1: Searching area is decided to extract lane edge information. Sobel operator is utilized to obtain edge detection. At this point, obtained edge is assumed as a road lane edge.

Step 2: The assumed lane edge is analyzed according to the edge verification algorithm. The verification utilizes the information such as lane width, adjacent lane color brightness and lane distance.

Step 3: Through edge verification process, the last remaining edge is accepted as a true lane.

Step 4: In the images from the camera, three data points, located at the same vertical image lane, are decided.

Step 5: Total six data points are decided for vehicle autonomous control motion.

Step 6: After successfully completing one frame of one road image, iterate the process from step one.

3. LATERAL CONTROL ALGORITHM

The requirments for safe running of autonomous vehicle are to recognize specific road patterns and to steer the

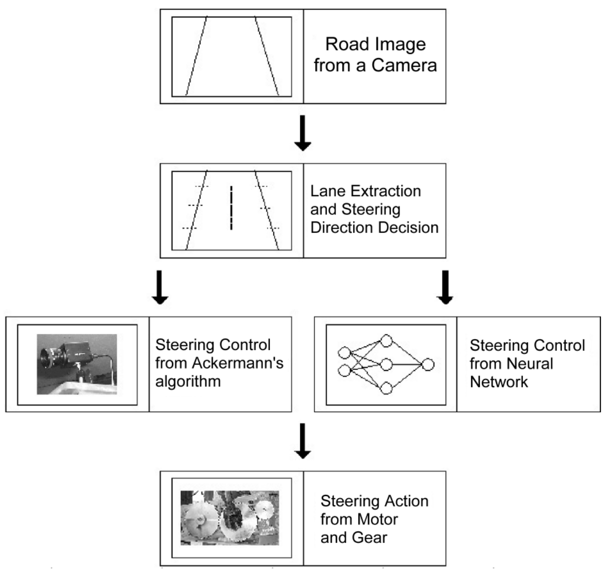

Figure 1. Structure of steering control system.

vehicle accordingly toward vehicle heading direction. In the present paper, for accurate lateral steering control, neural network control scheme obtained from expert drivers is utilized. Later, the proposed algorithm is compared with one obtained from lateral control scheme using kinematic relationships, *i.e.* Ackermanns steering angles. Figure 1 shows the schematic diagram for lateral autonomous vehicle control. In the following chapter, kinematic Ackermanns steering control algorithm shall be introduced first, and then neural network algorithm is explained later.

3.1. Steering Angle Calculation from Vehicle Geometry

In order to obtain steering angle using vehicle and camera geometry, several complex coordinate transformation is required. Also, accurate vehicle geometry data are necessary. To calculate accurate steering angle input, road image coordinate should be transformed into the vehicle coordinate first. Therefore, to steer the vehicle toward desired direction correctly, necessary steering angle is then determined from vehicle and steering geometry. If Δx_S, Δx are defined as lateral x-direction distances in the screen and in the real vehicle, respectively, then the following equation is obtained.

$$\Delta x = \frac{L}{f} \tag{1}$$

where L is a total length between camera and vehicle center, and f represents the focal length of the camera. Then, the turning radius R for lateral motion is obtained as

$$R = \frac{D^2}{2\Delta x} + \frac{\Delta x}{2} \tag{2}$$

where D stands for the horizontal component of L. Finally, turning angle α can be calculated as

$$\alpha = \tan^{-1}\left(\frac{l}{R}\right) \tag{3}$$

in which, l represents the wheel base length. The accurate steering angle calculation involves many vehicle data such as tire size, tire cornering force, tire pressure, suspension geometry, bush compliances and steering geometry. As it is very difficult to consider above mentioned data for calculating accurate Ackermanns angle calculation, only steering geometry, *i.e.* steering gear ratio and rack/pinion geometry and vehicle basic geometry, *i.e.* vehicle length and wheel tread are considered in the present paper.

3.2. Neural Network Algorithm

In the neural network algorithm for vehicular steering calculation, all the complex camera and vehicle geometry are ignored, and only human driver pattern data for lane following is utilized for vehicle steering. Therefore, it is possible to drive the autonomous vehicle as accurately as human driver's steering pattern. To get the human driver's steering pattern for specific vehicle speeds and roads, learning process is required for neural network model. In general, learning process is represented by back propagation in the neural network algorithm, and at the present paper, Levenberg-Marquardt neural network algorithm is utilized for fast convergence and accurate steering pattern for lane learning process. The Levenberg-Marquardt neural network algorithm is summarized as follows.

Step 1: According to all network input parameters network output values and corresponding errors are calculated. Also, all error square sum is obtained for all input parameters.

Step 2: Jacobian matrix is calculated.

Step 3: Using the below equation, $\Delta \underline{x}$ is obtained.

$$\Delta \underline{x} = [J^T(\underline{x}) J(\underline{x}) + \mu I]^{-1} J^T(\underline{x}) e(\underline{x}) \tag{4}$$

Step 4: Using $x + \Delta \underline{x}$, error square sum will be recalculated, where x is a parameter vector, J is a Jacobian matrix with the form of

$$J = \begin{bmatrix} \frac{\partial e_1(x)}{\partial x_1} & \frac{\partial e_1(x)}{\partial x_2} & \cdots & \frac{\partial e_1(x)}{\partial x_n} \\ \frac{\partial e_2(x)}{\partial x_1} & \frac{\partial e_2(x)}{\partial x_2} & \cdots & \frac{\partial e_2(x)}{\partial x_n} \\ \\ \frac{\partial e_N(x)}{\partial x_1} & \frac{\partial e_N(x)}{\partial x_2} & \cdots & \frac{\partial e_N(x)}{\partial x_n} \end{bmatrix},$$ μ is a control parameter,

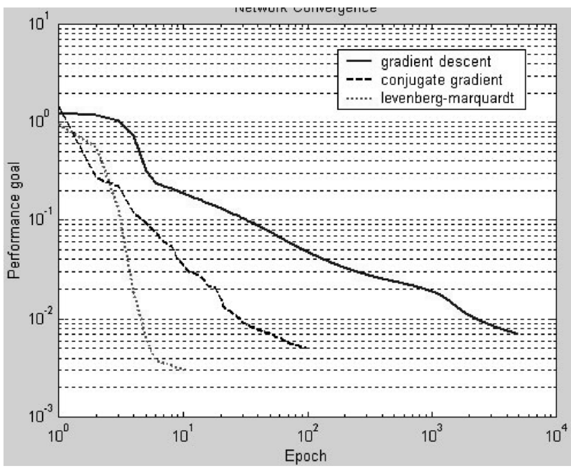

Figure 2. Comparison of Levenberg-Marquadrt algorithm with others in convergence point of view.

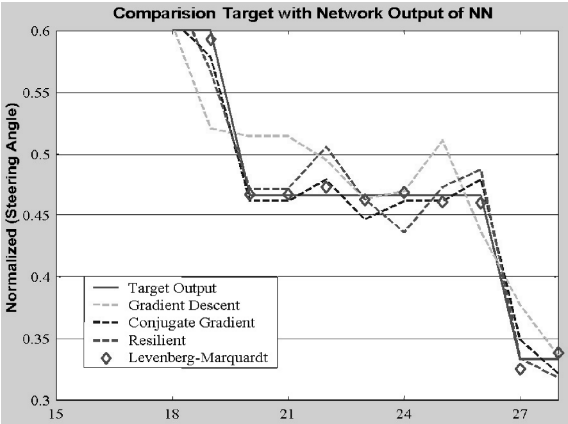

Figure 3. Comparison of Levenberg-Marquadrt algorithm with others in tracking point of view.

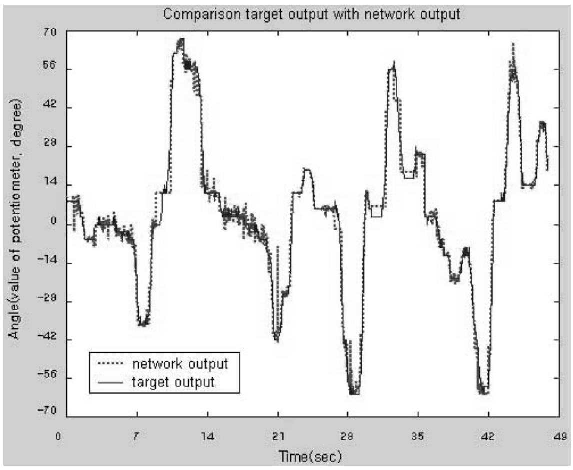

Figure 4. Comparison between network output and target output.

I is an identity matrix, and $e(\underline{x})$ is an error vector.

If newly calculated error square sum is smaller than the one obtained from step 1, decrease μ up to β, where β is a control parameter.

By inputting $\underline{x}=\underline{x}+\Delta\underline{x}$, new error square sum is calculated according to the step 1. If error sum does not decrease, increase μ up to β, and go to step 3.

Step 5: If gradient norm value is below the pre-defined limit value or calculated error square sum is lower than the predetermined error setup value, then the network system is considered to be successfully converged.

Figure 2 shows the convergence rate comparison with other neural network algorithms, *i.e.* gradient decent method and conjugate gradient one. From the figure, it is clear that the proposed neural network algorithm is superior in convergence point of view as well as in accuracy point of view. Figure 3 shows the tracking results between Levenberg-Marqurdt algorithm and other ones. From the figure, it is clear that Levenberg-Marqurdt algorithm is superior in tracking the target value compared with other methods. However, in the simulation, the other two algorithms had some difficulties in obtaining enough convergence rate. Considering accuracy and convergence speed, Levenberg-Marqurdt algorithm is a very good one for utilizing the autonomous vehicular control.

The neural network inputs are the lane feature-based 6 points obtained from camera image, and the outputs are the values of discrete potentiometer data for steering. Therefore, the neural network system has 6 inputs, and one output and 50 hidden layers. The input and output pattern data are normalized through bipolarization. Tangent sigmoid function was used as an active function, and total 2000 learning iteration was performed for system learning process. After completing back propagation, each weight functions in the layers are representatives for the steering control process for given load patterns, and even though new load profile is fed to the neural network controller, the system will output an appropriate steering control signal as human driver. After learning process, in order to verify the accuracy of the proposed controller, the same input pattern used for learning process is applied as an inputs, and comparison between the reference outputs obtained from human driver and ones through network system is performed. Figure 4 shows the comparison results between human drivers steering output obtained from sensor and the one from neural network system. The figure shows that the proposed neural network system follows human drivers steering pattern well for various road profiles.

4. AUTONOMOUS VEHICLE SIMULATION

The simulation was made according to the given road profile used for lane recognition, and two results were obtained: one from Levenberg-Marquardt neural network algorithm and the other from Ackermann's steering algorithm. The figures 5-7 show the results between two methods. In the figures the lane data were obtained from the image processing from real camera input and only left lanes were processed for simplicity. The right lane shows similar results. In the figures two methods show that they follow road lanes well and two methods have not shown big discrepancies. However, the neural network system's lateral steering characteristics obtained from human driver's experience show smoother lane changing than the ones obtained from Ackermann's method. Also, it is clear that the steering angle variation from Ackermann's method follows the given lane profiles more accurately then neural network one, but its steering action has lots of

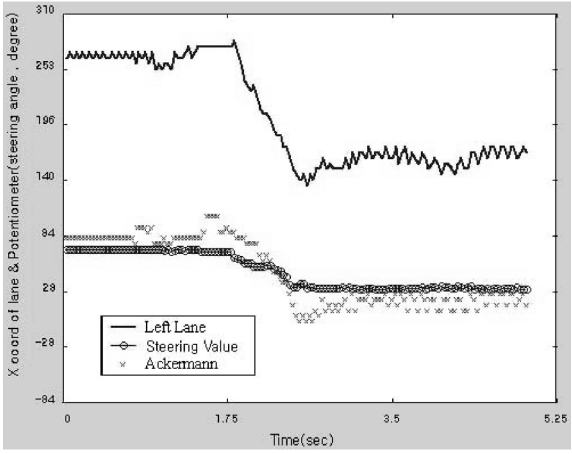

Figure 5. Lane following pattern 1.

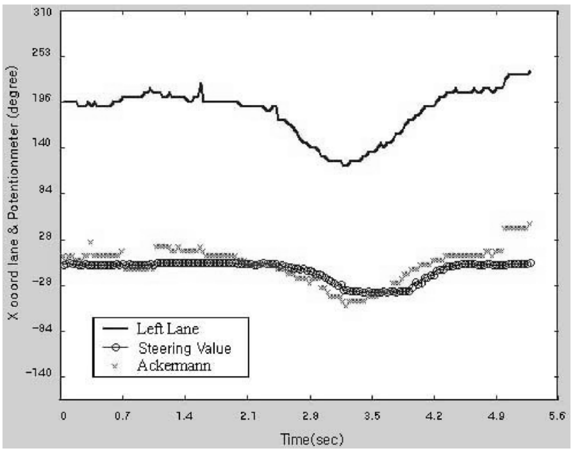

Figure 6. Lane following pattern 2.

high frequencies, which implies busy steering to result in much yawing motion for the vehicle. In the sense of ride comfort view point, the proposed neural network algorithm has much advantage than Ackermann's one, because the vehicle movement becomes smooth.

5. EXPERIMENTS

5.1. Proto Car Construction

The proto car for autonomous vehicle was specially built in order to apply and verify lateral autonomous control. The built vehicle has single driver seat and its engine has 125cc size. Front, double wishbone and rear, multi link suspension are adopted. For safety reasons, dual driving steering systems were designed and built. First one is for autonomous mode and the other is for manual steering mode. For the main CPU of the controller, desktop computer is used and other 80196 microprocessor-based controller is utilized for controlling of steering rack gear only. The steering rack was driven with stepping motor and its gear assembly.

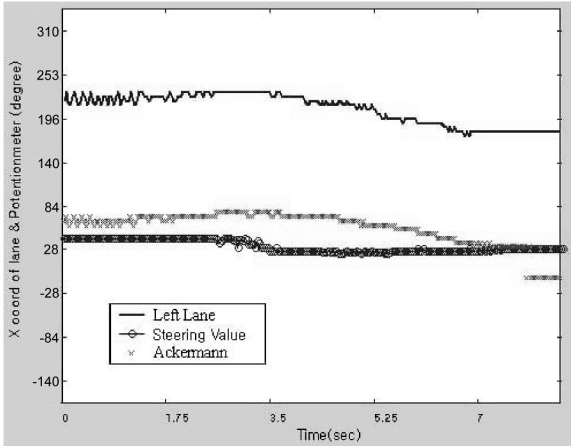

Figure 7. Lane following pattern 3.

Figure 8. Prototype of autonomous vehicle.

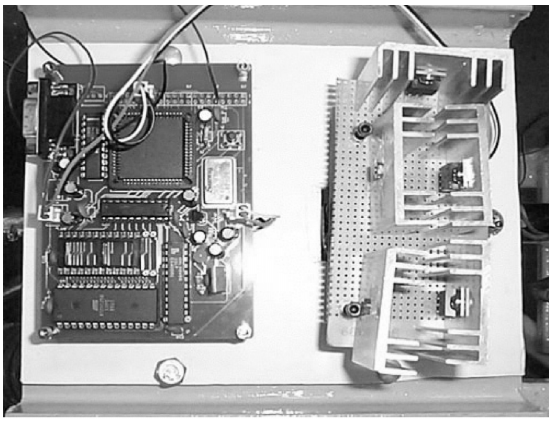

Figure 9. Electrical components.

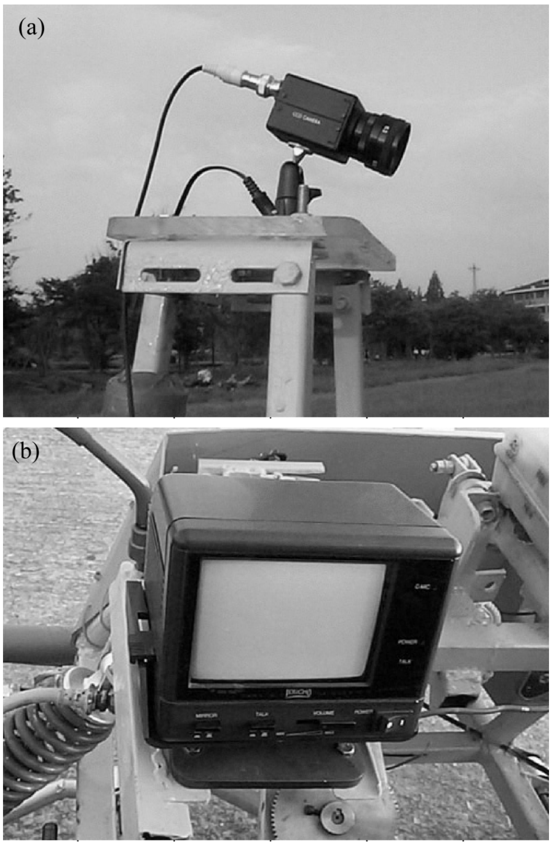

Figure 10. Vision system.

Camera was attached at the top of the vehicle and a TV monitor was used to check that the given road profile is appropriately processed. Figure 8 shows the photo of the proto car for experimenting of autonomous lateral action. Figure 9 shows motor controlled part composed of 80196 CPU and amplifiers, Figure 10 represents the photos of camera system, and Figure 11 shows steering system.

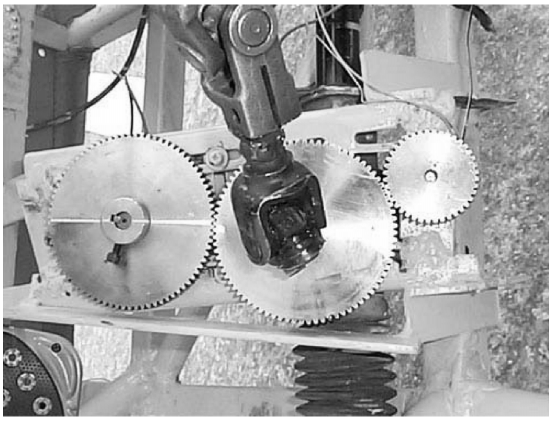

Figure 11. Steering system.

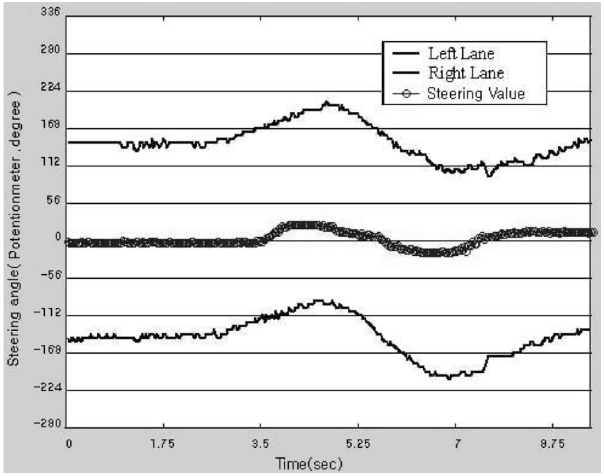

Figure 12. Lane following results.

5.2. Experiments

As the proto vehicle does not have the capabilities for controlling acceleration and brake motion, *i.e.* autonomous longitudinal motion at this time, human driver should control the vehicle's longitudinal motion. Only lateral motion was performed autonomously by the proposed neural network algorithm and given lane extraction method. Speed and braking control is now under study and full autonomous vehicle control results for the given proto vehicle will be presented soon. The proposed scheme based on neural network and lane extraction method shows adequate performance up to the maximum speed of 40 km/hr. The image processing was performed at the rate of 28.5 times per second. Figure 12 shows the results of autonomous lane following. It was verified that the proto vehicle with the proposed algorithm run smoothly and autonomously up to the speed of 40 km/hr. Even at higher speed, the proto vehicle can be run autonomously, however, the test has not been performed for safety.

6. CONCLUSIONS

The present paper describes one of autonomous lateral vehicle control scheme using CCD camera image input using Levenberg-Marquardt neural network algorithm. In order to increase image processing speed and steering accuracy, only partial image data was processed. Three discrete data points at each vertical lane are extracted and total six featured data points representing left and right lane are utilized for calculating steering angle. Sobel operator is adopted for extracting lane edges and lane verification algorithm is applied to get the featured lane characteristics.

Two lateral control algorithms are applied for simulation: Levenberg-Marquardt neural network algorithm and Ackermann's geometric algorithm. It is proven that the former method has much smoother yawing control capability since it is very similar to human driver's steering action. In order to verify the proposed Levenberg-Marquardt neural network algorithm and its capabilities, proto vehicle was built and tested. The experiments showed that the proposed Levenberg-Marquardt neural network algorithm with six digital featured lane information performed lateral control of autonomous vehicle well up to speed of 40 km/hr.

ACKNOWLEDGEMENT–This work was carried out as part of research projects supported by Chonnam National University's BK21 in year of 2000. The authors are grateful for the support and express special thanks to the undergraduate students of Chonnam National University, Department of Mechanical Engineering, who spent times to build proto type vehicle.

REFERENCES

Hagan, M. T. and Menhaj, M. B. (1994). Training feed-forward networks with marquardt algorithm. *IEEE Transactions on Neural Networks* **5**, **6**, 1134-1139.

Haykin, S. (1999). Neural Networks: A Comprehensive Foundation. Prentice Hall.

Kehtrarnavaz, N. (1998). A transportable neural network approach to autonomous vehicle following. *IEEE Transacations on Vehicular Technology* **47**, **2**, 367-373.

Kim, E-S (1999). Steering Speed and Angle Control of Autonomous Vehicle for Various Road Profiles. PhD Dissertation, Chonnam National University.

Kuan, D. (1988). Autonomous robotic vehicle road following. *IEEE Transactions on Pattern Analysis and Machine Intelligence* **10**, **5**, 233-239.

Lim, Y-C., Ryoo, Y-J., Park, J-K. and Moon, C-J (1996). Visual control of an autonomous vehicle using neural network. *IEEE Proceedings of the IECON96*, 1064-1069.

Manigel, J. and Leonhard, W. (1992). Vehicle control by computer vision. *IEEE Transactions on Industrial Electronics* **39**, 181-188.

Moon, S-H. (1997). Autonomous Control for Mobile Objects. PhD Thesis, Korea University.

Passino Kevin, M. (1995). Intelligent control for autonomous system. *IEEE Spectrum* **113**, 55-62.

Pitas, I. (1995). Digital Image Processing Algorithms. Prentice Hall.

Pomerleau, D. A. (1997). Neural Network Perception for Mobile Robot Guidance, Kluwer Academic Publishers.

Ryoo, Y-J. (1998). Autonomous Vehicle Control using Comparative Division-based Neural Network. PhD Dissertation, Chonnam National University.

Ryoo, Y-J. and Lim, Y-C. (1999). Neuro-fuzzy control system for vision-based autonomous vehicle. *IEEE International Fuzzy System Conference*, 1643-1648.

Tsugawa, S. (1994). Vision-based vehicles in japan machine vision systems and driving control systems. *IEEE Transactions on Industrial Electronics* **41**, 398-405.

Yang, S-H., Harashima, F., Lim, Y-C., Cho, K-Y. and Ryoo, Y-J. (1996). Steering control system for autonomous road vehicle using fuzzy neural network. *Transactions of Japan IEEE* **1150**, **11**, 1369-1373.