Adaptive Type-2 Fuzzy Neural Network for Lateral Vehicle Control Design in Automated Driving

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***Abstract*—The automated driving control system plays an important role in autonomous vehicles. So far, control parameters in such systems mainly rely on modeling the interaction between the subsystems to derive the proper adaptive law. In this study, we propose an adaptive steering compensation scheme based on the type-2 fuzzy neural network (T2FNN) with the sliding mode learning algorithm to yield effective compensation control by learning online interactions from the measured feedback error. The conducted simulation will verify the adaptability and robustness of the proposed approach and test under several driving conditions.**

Keywords—Autonomous driving, steering compensation, type-2 fuzzy systems, adaptive control, fuzzy neural network.

I. INTRODUCTION

To solve traffic problems such as traffic congestion, many developed countries actively undertake research on the intelligent transportation system (ITS), where the autonomous vehicle control system is essential. Because the steering control system directly affects a vehicle's driving direction, it plays an important role in the autonomous vehicle control system. Vehicles may run into others if the system is not well designed. To the present, steering control systems have introduced a lot of advanced techniques; however, many of them cannot tune the control parameters online to cope with the complex driving environment. Therefore, this study proposes a steering control based on the type-2 fuzzy neural network (T2FNN) to make a steering control system adaptive and able to deal with the uncertainty and nonlinear problems of vehicle systems.

As for the structure, the combination of a conventional preview control and an intelligent controller T2FNN is chosen. Such a structure is called feedback error learning (FEL), it was originally proposed in [1] for robot control in which a neural network-based controller works with a PD controller. This study presents a further extension of the SMC theory. Instead of updating parameters in T2FNN by minimizing an error function, this approach derives updating rules from SMC theory to enforce the error to satisfy the stable equation. Moreover, the stability of this learning algorithm is proved through the Lyapunov energy function.

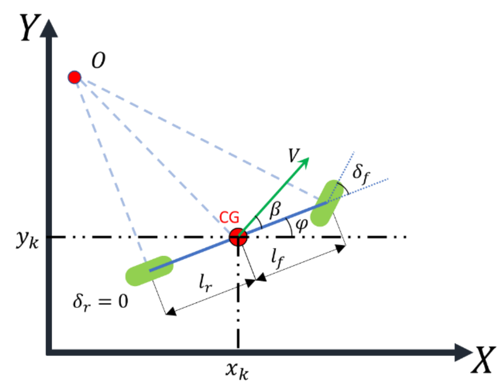

Fig. 1 Kinematic bicycle model.

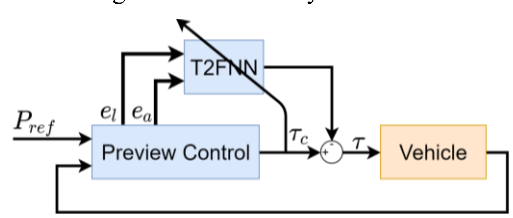

Fig. 2 The proposed steering compensation scheme.

II. VEHICLE STEERING CONTROL SYSTEM

A. Vehicle Kinematic Model

To ensure the performance of the controller, a vehicle mathematic model should be created according to vehicle kinematics and vehicle steering system. The kinematic mathematic model in this paper is simplified into the bicycle model [2], in which we only consider the motion of the vehicle on a plane. The schematic diagram of the kinematic bicycle model is presented in Fig. 1 where $l_f$represents the distance between the front axle and the *CG* of the vehicle, l_f represents the distance between the rear axle and the *CG* of the vehicle, V represents the velocity, φ represents the yaw angle of the vehicle, δ_f , and δ_r, respectively represent the steering angle of the front wheel and the steering angle of the rear wheel, and β is the slip angle.

This work was financially supported by National Science and Technology Council, Taiwan, under Grant No. NSTC 111-2221-E-027-147-MY2.

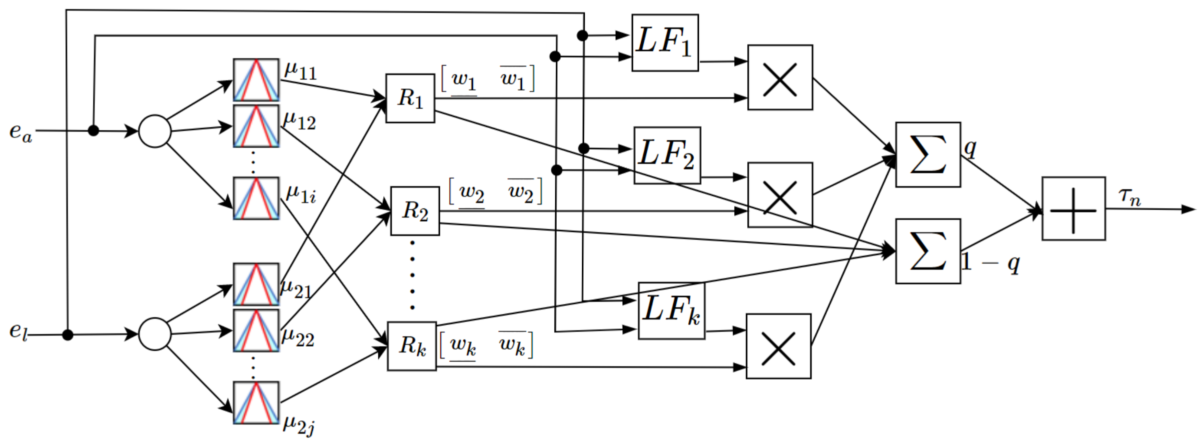

Fig. 1 Architecture of the T2FNN control system.

B. Architecture of Steering Control System

In Fig. 2, the proposed steering control system consists of a preview controller and a T2FNN controller. The first thing is to calculate the steering angle of the front wheel through the current vehicle state and reference trajectory P_{ref} derived from the preview controller. Second, the lateral offset e_l and the offset area e_A of the preview point of the vehicle will be fed into T2FNN controller which will calculate the compensation of the steering angle of the front wheel. Finally, a control strength, calculated based on the results from the preview controller and the T2FNN controller, is then served as the input to the vehicle system.

C. T2FNN Controller

The structure of the designed T2FNN is shown in Fig.3. This T2FNN controller is based on a fuzzy system architecture [3]. The interval T2FNN considered in this paper uses type-2 triangular MFs in the antecedent part and uses numerical analysis to defuzzify in the consequent part. The fuzzy rule R_{ij} of a zeroth-order type2 TSK model with two input variables can be defined as follows:

$$R_{ij} : if\ e_l\ is\ \tilde{A}_{1i}\ and\ e_a\ is\ \tilde{A}_{2j}\ then\ f_{ij} = d_{ij} \tag{1}$$

where $\tilde{A}_{1i}$ and $\tilde{A}_{2i}$ represent interval fuzzy sets. T2FNN includes seven layers. In Layer 1, input signals are fed into the system, which is the lateral offset error e_l and offset area e_A. In Layer 2, the membership values $\bar{\mu}(x)$ and $\underline{\mu}(x)$for two inputs are determined. Layer 3 calculates the firing strength of each rule R_{ij}. Layer 4 calculates the outputs of the consequent part by using two input signals and linear functions. In Layer 5, firing strengths $\underline{w_{ij}}$ and $\overline{w_{ij}}$ are multiplied by linear function f_{ij}. In Layer6, there are two adders, one of them calculates the sum of Layer 5, and the other calculates the sum of Layer 3. The last layer, Layer 7, calculates the output of the system.

D. T2FNN Parameters

T2FNN in this paper is an online tuning algorithm based on SMC theory [4] which makes this steering control system adaptive. This T2FNN is a nonlinear regulator which reaches the convergence conditions through tracking error and makes the nonlinear system converge through compensating. Considering the learning error $\tau_c(t)$ will converge to zero, a time-varying sliding surface S_c can be defined as (2), and the adaptive law for self-tuning the T2FNN parameters can be derived from sliding mode learning algorithm.

$$S_c(\tau_n, \tau) = \tau_c = \tau_n + \tau = 0 \tag{2}$$

III. SIMULATION AND VERIFICATION

In this study, we build the proposed steering control system on a vehicle simulator CarSim, which is widely used to conduct accurate and realistic simulations of vehicles. Through the dynamics in CarSim approximating real vehicles and road testing, the designed steering compensation system can be evaluated in terms of performance on different road conditions and driving scenarios created in CarSim.

REFERENCES

[1] M. Kawato, Y. Uno, M. Isobe, and R. Suzki, "Hierarchical Neural Network Model for Voluntary Movement with Application to Robotics," *IEEE Contr. Syst. Mag.*, vol. 8, no. 2, Apr. 1988, pp. 8–15.

[2] R. Rajesh, *Vehicle Dynamics and Control*. US: Springer, 2012.

[3] M. B. Begian, W. W. Melek, and J. M. Mendel, "Parametric Design of Stable Type-2 TSK Fuzzy Systems," in *Proc. North Amer. Fuzzy Inf. Process Soc.*, May. 2008, pp. 1–6.

[4] V. I. Utkin, *Sliding Modes in Control Optimization*. New York, 1992.

[5] E. Kayacan, E. Kayacan, H. Ramon, O. Kaynak, and W. Saeys, "Towards Agrobots: Trajectory control of an autonomous tractor using Type-2 fuzzy logic controllers," *IEEE/ASME Trans. Mechatronics*, vol. 20, no. 1, Feb. 2015, pp. 287–298.