International Journal of Applied Engineering Research
ISSN 0973-4562 Volume 10, Number 9 (2015) pp. 23291-23296

http://www.ripublication.com

A Study on Tracking Control of Next-Generation Transportation Systems on Connected Buses Equipped with 4WS

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Abstract

In this study, I propose a new method for controlling the steering equipped with 4WS (Four Wheel Steering System) in order for all the tread centers of a vehicle to travel in the same trajectory. The steering control system is composed of feed-forward and -back. By applying a sliding mode controller, which is one of the non-linear control methods, the steering angle is corrected to ensure high robustness. The control system is verified by a numerical simulation, based on the vehicle dynamics model of the degrees of freedom.

Keywords: Vehicle Dynamics, Four Wheel Steering, Attitude Control, Sliding Mode Control, Zero Off Tracking, Inverse Problem

1. Introduction

It is difficult to secure land and expand roads in cities filled with crowded streets and expensive land. Therefore, the expansion of public transport was required as an effective measure to reduce the number of vehicles. Although a variety of transportation systems are proposed, there is a problem that it takes enormous investment in facilities, in building a new transportation system. So, promoting the convergence of the existing transportation system, the new transportation systems with high speed and punctuality have been introduced in respective regions. For this reason, it can be seen that the transport system is useful when using large vehicles such as buses. In terms of the system operable even in normal road sections, using buses also is superior compared to cost-effectiveness, such as construction costs and other operating expenses. [1] [2]

This study is conducted using a public transportation system with a transport capacity of the medium control technology, to which automatic operation applied. When the ranks of vehicles are driving, in order for the tread centers of the front and rear wheels to run in the same orbit, 4WS (Four Wheel Steering System) is to be applied to large connected buses. In this study, the steering control system using the sliding mode control is verified by numerical simulation. Here, the verification of the steering control system, using the sliding mode control by numerical simulation, using the vehicle dynamics model of degrees of freedom, and the results of the tracking performance for a target course on a single vehicle are reported.

2. Advanced guideway bus system

The system consists of mechanically connected vehicles, as shown in Figure 1. The vehicles are equipped with a 4WS (Four Wheel Steering System) in order to automatically run on dedicated tracks along the same orbit, with the same front and rear tread centers. In addition, each vehicle has an independent control system. The driving road detects the position information of the vehicle based on the equivalent magnetic markers embedded with equivalent intervals and controls the steering. The vehicle is equipped with instruments, such as a gyro sensor that detects vehicle conditions required for the steering control and a magnetic sensor for detecting magnetic markers. [3]

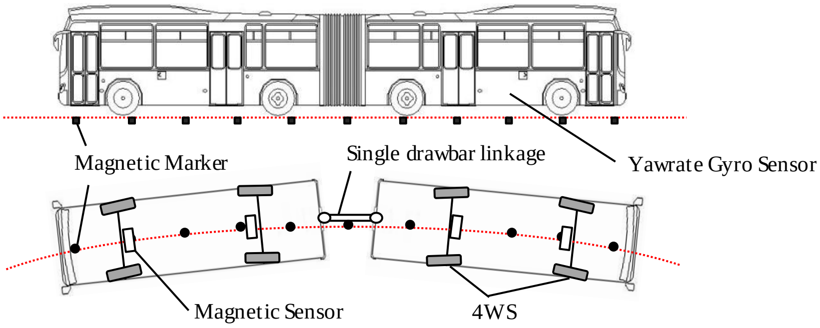

Fig. 1: Advanced guideway bus system

3. Steering control system

The steering control system, as shown in Figure 2, is the configuration of the feed-forward system and feed-back system, and will be described in detail below.

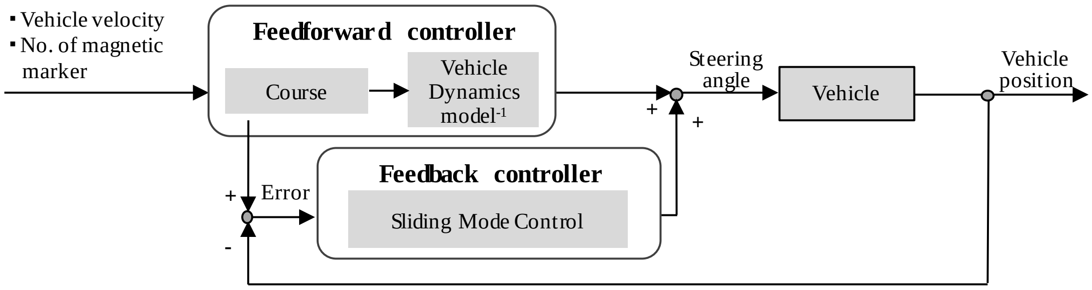

Fig. 2: Block diagram of steering control system

3.1 Feed-forward control system

Feed-forward steering pattern in the control system is determined by the linear characteristics of the target course and the vehicle dynamics. If the wheel treads and wheel center treads travel along the dedicated orbit, the attitude angle of the vehicle, with respect to any position in the course, is determined indiscriminately since both the front and rear points of the vehicle are restrained. Thus, the coordinates and attitude angles of the vehicle are functionalized when the magnetic sensor of the vehicle passes over magnetic markers on the road, and the functionalized figures are stored in the control system as database.

Using this data, based on the updated position information and updated speed information of the vehicle, the time change of the vehicle state quantity is calculated. Using the vehicle state quantity, the steering angles of the front wheels and the rear wheels are calculated by reversely calculating a plane equation of the second degree of freedom vehicle dynamics model shown in Figure 3.

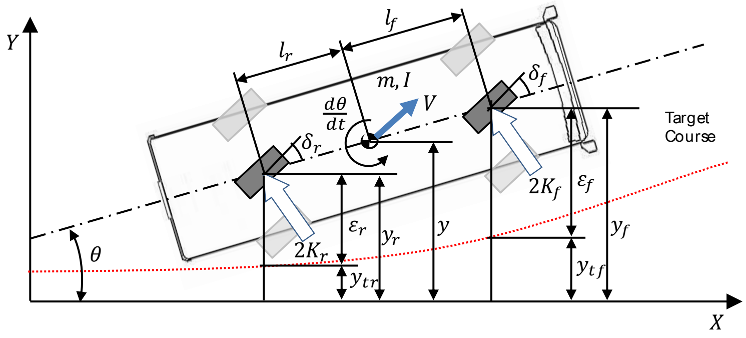

Fig. 3: Vehicle dynamics model

3.2 Feed-back control system

In the feed-back control, if the horizontal deviation is caused due to the velocity change between the magnetic marker, the characteristic change of the vehicle, the initial drift, and the horizontal deviation caused by external forces at the connected points of the vehicle, the corrected steering angles and the steering angles of feed-forward are added based on the feed-back of the horizontal deviation. Since large-sized vehicles have uncertain factors, including the uncertainties and the unknown parameters, such as the load changes according to the number of passengers, the characteristic change of tires, and the changes in the system according to various specifications, control systems are required to confirm a high robustness. In this study the practicality is enhanced, and a sliding mode control is applied by using the robust control that can be relatively easily introduced.

Here, an extension system, in which the integral value of the difference of horizontal displacement of the front and rear tread center, and course objectives are added to state variables in order to apply the target tracking servo system to the steering control system, is represented as the following equation:

$$\begin{bmatrix} \dot{z} \\ \dot{x}_1 \\ \dot{x}_2 \end{bmatrix} = \begin{bmatrix} 0 & -C & 0 \\ 0 & A_{11} & A_{12} \\ 0 & A_{21} & A_{22} \end{bmatrix} \begin{bmatrix} z \\ x_1 \\ x_2 \end{bmatrix} + \begin{bmatrix} 0 \\ 0 \\ B_2 \end{bmatrix} u + \begin{bmatrix} I_t \\ 0 \\ 0 \end{bmatrix} y_t$$

In this equation, the switching function is defined and switching hyper plane, in which sliding mode takes place, is set up. The sliding mode control input is composed of the linear feed-back control and the non-linear control. Furthermore, the design of the switching hyper plane was designed using the 'pole placement method' so that the low-order sliding mode system can be stable. When the vehicle passes through the magnetic markers, the center position of the vehicle body in the front and rear wheels, and the width of the target course deviation information are obtained. The horizontal deviation between the magnetic markers herein is estimated by dead reckoning using a vehicle state quantity. The horizontal slip angles of the vehicle body which are difficult to measure are estimated by using a state observer.

4. Simulation

The simulation system used in this study is shown in Figure 5 . The dynamics of the large vehicle motion simulation software, TruckSim, were used as a vehicle model. The vehicle model has a number of parameters to simulate the behaviors of actual vehicles in running tests. By calculating steering angles from the steering control system for a vehicle configured to Simulink, each vehicle model is provided. The dimensions of the vehicle are shown in Table 1. Driving conditions were set as single lane change as shown in Figure 6 and the advance functionalization was made in order to calculate the feed-forward steering. Lane Change distance L was simulated at intervals from 10 m to 60 m for the distance of 100 m. The running speed was constant at 40 km/h, and magnetic markers were installed at 2 m intervals on the course. The error rate of detection of the degree of horizontal deviation of the vehicle magnetic sensor has been set as ± 10 m allowance for the target course, with the probability set at regular distributions.

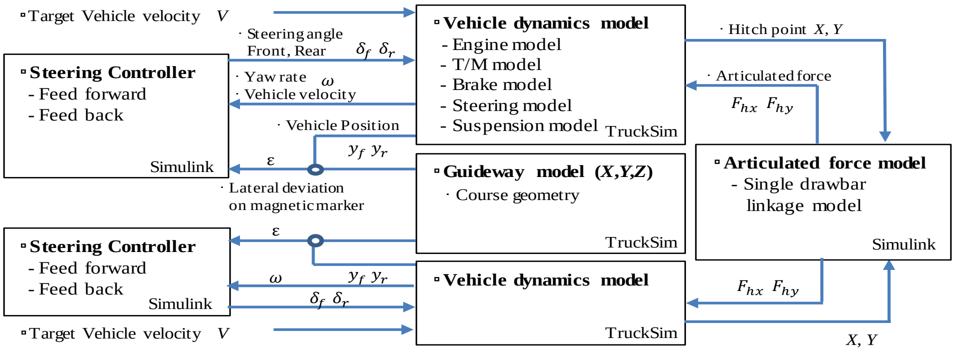

Fig. 4: Simulation system

Table 1: Vehicle specifications

Parameter	Symbol	Value	Units	Parameter	Symbol	Value	Units
Front axle to vehicle c.g.	l_f	2.05	*m*	Cornering stiffness	K_f	199630	*N/rad*
Rear axle to vehicle c.g.	l_r	1.66	*m*		K_r	248193	*N/rad*
Vehicle mass	*m*	8300	*Kg*	Yaw moment of inertia	*I*	28225	$Kg{\cdot}m^2$

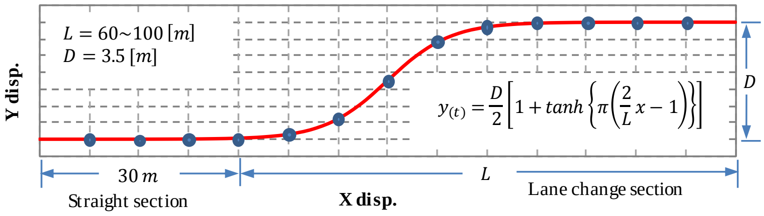

Fig. 5: Target path

5. Result and discussion (Tracking Performance of a single vehicle)

Here, to confirm the basic performance of the steering control system, a simulation was carried out on a single vehicle. Under the condition that lane change distance is 80 m, the results of the vehicle response are shown in Figure 6 (left). The maximum deviation is suppressed as 20 mm by appropriate steering control. Considering that this simulation is considered to reproduce actual driving exactly, this result ensures that the tread centers of the front and rear wheel drove on the same orbit. In relation to the lane change distance and course tracking performance, the integrated square error of the horizontal deviation and the maximum deviation (abs) are shown in Figure 6 (right). As shown in Figure 6, it was confirmed that the more the lane change distance is reduced, the more the integral square error is increased.

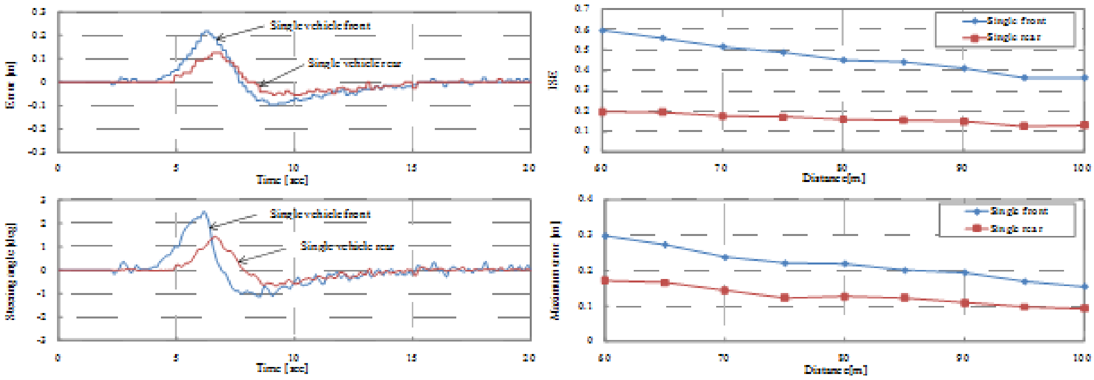

Fig. 6: Simulation results of the single vehicle

6. Conclusion

The steering control system with the sliding mode was installed on a single large bus with a four-wheel steering system. According to the results of numerical simulations using vehicle dynamics model of freedom, the center points of the front and rear tread were feasible to run along the same trajectory.

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