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A Study on Trajectory Estimation for the Next Generation Interconnected Bus in the Case of Vehicle Steering Control System Failure

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Abstract

The vehicle is equipped with the all-wheel steering system in order for all the tread centers to run in the same trajectory. The steering control system is composed of a feed-forward and feed-back. Also, correcting steering angles ensure high robustness by applying a sliding mode controller, a nonlinear control method. In such control systems, by conducting numerical simulations based on the vehicle dynamics of the multi-degree of freedom model, each of the vehicle trajectories for the steering-control failure was investigated.

Keywords: Vehicle Dynamics, All-Wheel Steering, Attitude Control, Sliding Mode Control, Zero Off Tracking

1. Introduction

There are connected buses, guideway buses, AGT (Automated Guideway Transit), and the LRT (Light Rail Transit) as medium-range domestic and international passenger transports between cities, transporting a small or medium number of passengers. The transportation system is mobility, punctuality, and carrying capacity, etc. Each has its own superior advantage. With the autonomous driving, recently being actively investigated and having advantages over conventional transport systems, the introduction of ITS (Intelligent Transport System), or AHS (Automated Highway System) promote the development of basic systems for autonomous driving. IMTS in Japan and APTS in the Netherlands are test-running and running the basic systems. [1] [2]

This study focuses on a public transport capable of transporting a small and medium number of passengers with the automatic driving control technique applied.

With the ranks of the vehicles driving, the all-wheel steering system is applied on a large connected bus in order for the centers of the front and rear wheels to travel in the same orbit. Here, we report the results of investigation of the driving trajectory when steering control fails in the numerical simulations based on the vehicle dynamics model of the multi-degree of freedom.

2. All-wheel steering guideway bus system

Figure 1 shows an outline of a vehicle guidance system that is assumed in the present study. In this system, the vehicles drive along the dedicated track, where magnetic markers are embedded at equal intervals and multiple large buses are mechanically connected using single drawbars. The vehicle automatically runs along the dedicated track with the front and rear wheel tread centers traveling in the same orbit. Each vehicle has an independent control system. An all-wheel steering system is mounted on the vehicle in order to achieve the required functionality optimized for the road alignment. On the road, the position information of the vehicle is detected and the steering is controlled based on the magnetic markers embedded on the road at equivalent intervals. Magnetic sensors for detecting magnetic markers and necessary instruments, including the gyro sensor to detect the vehicle states necessary for the steering control, are mounted on the vehicles [3].

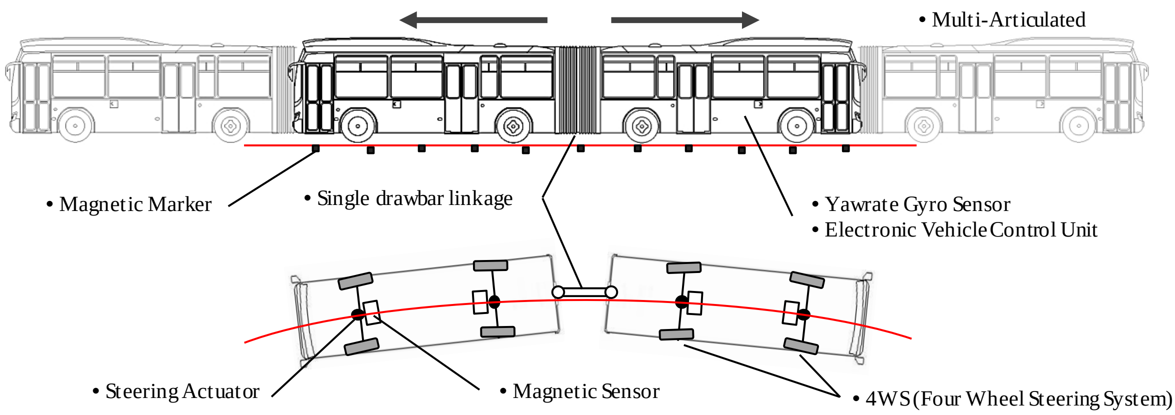

Fig. 1: Automated guideway bus system

3. Steering control system

3.1 Feed-forward control system

The steering patterns making commands in the feed-forward control system are determined by linear vehicle dynamics and characteristics of the target course. When the front and rear wheel tread centers travel to draw the same orbit, the attitude angles of the vehicle, with respect to any course positions, are determined uniformly, since the two dots in the front and the rear of the vehicle are restrained with respect to the target course. Therefore, when the vehicle passes the magnetic markers, the coordinates and the postures of it are functionalized and entered into the control system as data. Using this data, based on sequentially updated speed information and location 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 the equation of the plane of the vehicle dynamics model, with two degrees of freedom station.

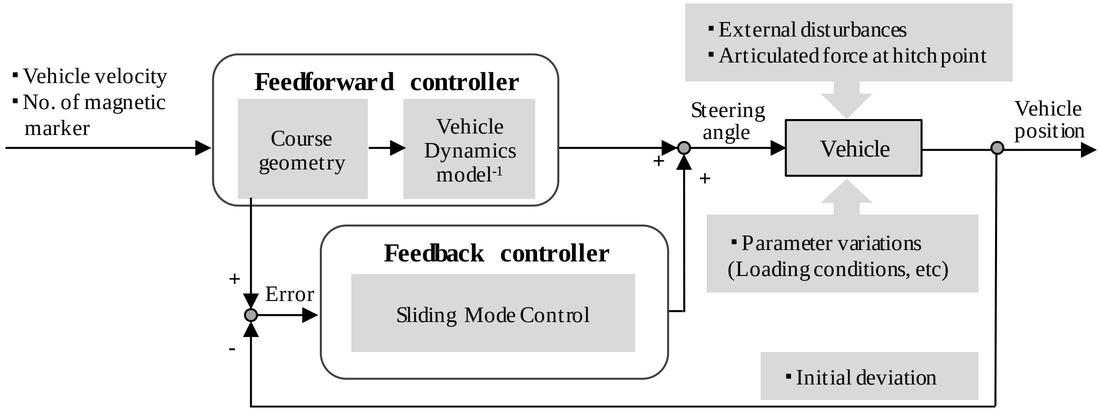

Fig. 2: Block diagram of steering control system

3.1 Feed-back control system

In feed-back control, when changes in the dynamics of the vehicle not considered in feed-forward and horizontal deviation caused due to external force resulting from the connected point occur, modified steering angles are added to the steering angles of the feed-forward after feeding back the difference. Here, we applied a sliding mode control using the robust control that can be relatively easily introduced. When passing through the magnetic markers, the center position of the vehicle at the position of front and rear wheels, and the width of the target course deviation information are obtained. The horizontal deviation between the magnetic markers is estimated based on dead reckoning using a vehicle state amount. The horizontal slip angles of the vehicle body, which are difficult to measure, are estimated using a state observer.

4. Steering control system

The simulation system used in this study is shown in Figure 5. The vehicle movement model is made using a dynamic model of heavy vehicle movement simulation software, TruckSim. Steering angles calculated by the steering control system configured by Simulink are provided to each vehicle model. The dimensions of the vehicle are shown in Table 1. Magnetic markers were embedded at intervals of 2 meters on the course. Detecting degree of the vehicle magnetic sensor for horizontal deviation was set as a ± 10 m error with respect to the target course to achieve a probability of regular distribution. A curved road is designated as the test course as shown in Figure 5, and functionalization was done in advance in order to calculate the feed-forward steering.

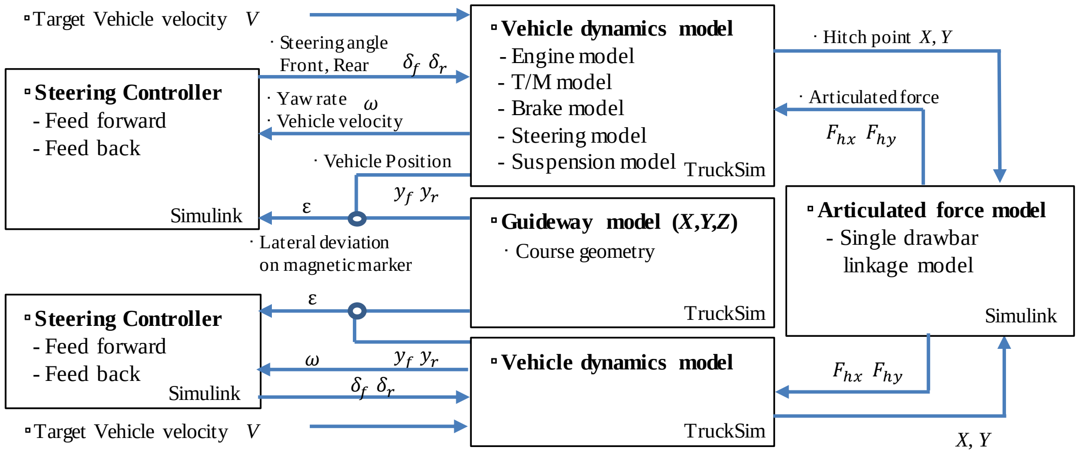

Fig. 3: Simulation system

Table 1: Vehicle specifications

Parameter	Value	Units	Parameter	Value	Units
Vehicle length	6.99	*m*	Cornering stiffness	199630	*N/rad*
Front axle to vehicle c.g.	2.05	*m*		248193	*N/rad*
Rear axle to vehicle c.g.	1.66	*m*	Vehicle mass	8300	*Kg*
Front hitch point	3.875	*m*	Length of drawbar	1.4	*m*
Rear hitch point	3.115	*m*	Yaw moment of inertia	28225	$Kg{\cdot}m^2$

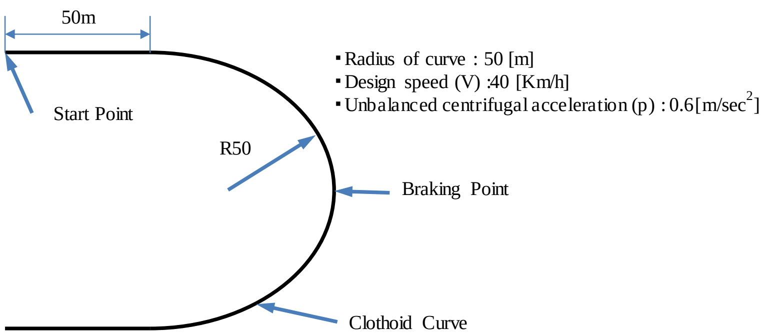

Fig. 4: Target course

4.1 Reviewing estimated travel patterns of the vehicle when the control system fails

The travel pattern of the vehicle was reproduced from the time of braking to a standstill when a failure mode occurs while a large connected bus is running along the dedicated track at a constant speed of 40 Km/H. The conditions are as follows:

Condition 1. Control system normal operation	Condition 3. Subsequent vehicle wheel control systems fail
Condition2. Preceding vehicle wheel control systems fail	Condition 4. Subsequent vehicle wheel control systems fail

The front wheel failure of the preceding vehicle is excluded from this review because the driver can manually steer. Braking deceleration is set to be 0.3 G, in consideration of the safety of passengers. The moment the front wheels of the preceding vehicle pass the 50% position of the curved distance of the total distance is set as the time for a fault to occur. The steering angle is fixed as the angle at which the steering failure occurs. Figure 5 shows a horizontal deviation according to various conditions. Although condition 2 and condition 4 have shown a similar horizontal deviation to that of Conditions 1, the front wheel control system malfunction of the subsequent vehicle in condition 3 showed the most notably high horizontal deviation.

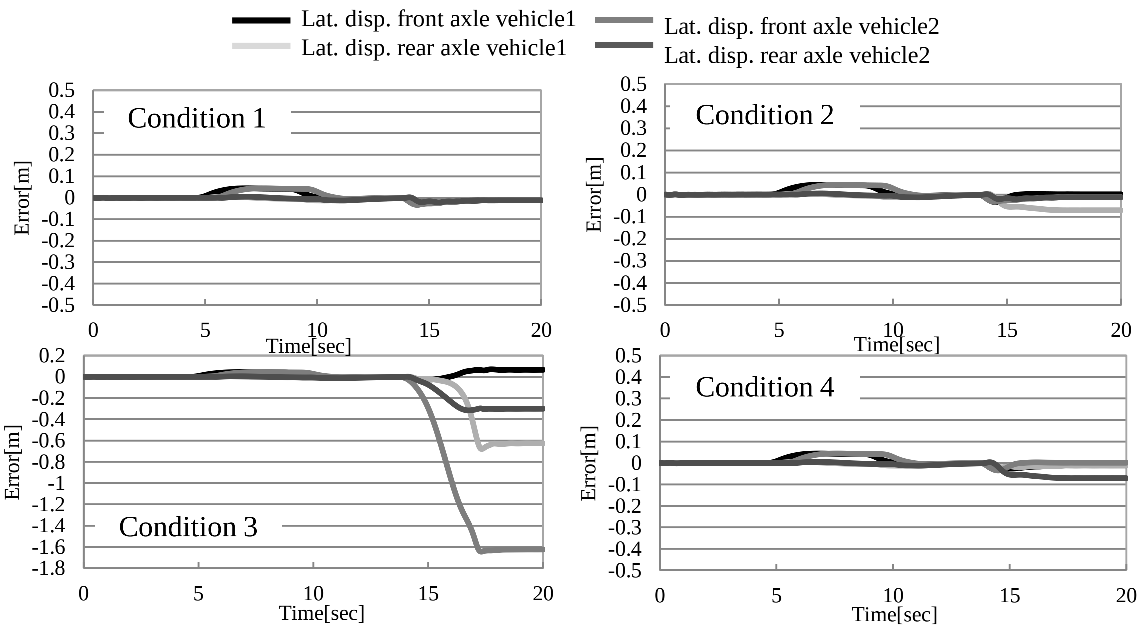

Fig. 5: Simulation results

5. Conclusion

After a review of the vehicle trajectories in case of steering control failure using the numerical simulation based on all freedom dynamic role model, in which the all-wheel steering system is applied to a large connected bus, if a front wheel steering device of the subsequent vehicle is out of order, the departure figures from the target course are confirmed to be the highest, which requires a review to come up with the measures to handle the problem.

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