Modeling of Agricultural Tractor-Trailer Combinations for Development of Autonomous Driving Control on Rough Terrain

Ryota Horie [1)] Marta Niccolini [2)] Alfredo Argiolas [2)] Edoardo Sorelli [2)] Kazuaki Hirasawa [1)]

1) YANMAR HOLDINGS, Co. , Ltd.
2481 Umegahara, Maibara, Shiga, 521-8511, Japan
2) YANMAR R&D EUROPE S.R.L.
Viale Galileo 3/A, 50125, Firenze, Italy

KEY WORDS: **vehicle dynamics, special vehicle, motion control,** Model Based Development [B1]

Demand for autonomous driving control systems on agricultural tractor-trailer combinations is increasing. When a controller is developed, the performance can be predicted since the preliminary stage using plant models which simulate the behavior of the controlled system. This Model Based Development approach can save time and costs for control development and testing. In this study, a plant model which can predict the dynamics of agricultural tractor-trailer combinations, travelling on rough terrain, has been developed by reflecting the effect of slip and load transfer on sloped fields into friction forces between wheels and road. The simulation model also integrates joints position constraints between the tractor and the trailer into the motion equations.

The developed tractor-trailer combination model calculates position (longitudinal, lateral position, and yaw angle) of tractor and trailer based on tractor longitudinal velocity and steering angle information. It was assumed that the tractor had 4 wheels, while the trailer had 2 wheels; the simulation model calculates tire forces in longitudinal and lateral direction separately. Ground surface deformation was ignored, and operating point of tire force was set to the bottom of the tire. Tire forces are calculated linearly with slip ratio or slip angle on each wheel as long as they don't exceed maximum friction force. In calculating the vehicle dynamics on sloped fileds, each vehicle's slip was considered based on the component of gravity force along slope direction. Moreover, load transfer on each wheel due to inclination angle are considered by calculating the wheel's vertical load. These vertical loads affect tire forces. Once contact force under wheels are computed, motion of tractor and trailer is obtained by solving Differential Algebraic Equation where joints position constraints between the tractor and the trailer are integrated.

In order to validate the simulator, several tests have been executed with the actual tractor. Fig.1 and Fig.2 are examples of comparison between test and simulation results. Fig.1 shows a result, where tractor traveled with constant steering angle (30 deg) and constant velocity (5 km/h) on rough terrain with inclination. The inclination angle of the terrain was around 10 deg. In Fig.1, blue line is tractor's position on simulation result while red line means tractor position in test acquisition. The ground was inclined in x-axis direction, and $+x$ direction represents lower side. When tractor started to run, initial position was $(x,y) = (0,0)$; initial yaw angle was 246 deg in anticlockwise from $+x$ direction. The tractor position error was accumulated based on error of tractor's lateral velocity. Fig.2 shows tractor's longitudinal and lateral velocity, and the lateral velocity error was 0.51 km/h (RMS error).

Another test result has been obtained with an autonomous driving control system. In the test, straight lines were set on rough terrain with lateral inclination as tractor's target trajectory. The inclination angle of the terrain was around 10 deg. The controller gave actual tractor steering input to follow the target line. Simulation result was also obtained with same controller and plant model. In this case, tractor's position error was 2.4 cm (RMS error) and 5.6 cm(Maximum error) .

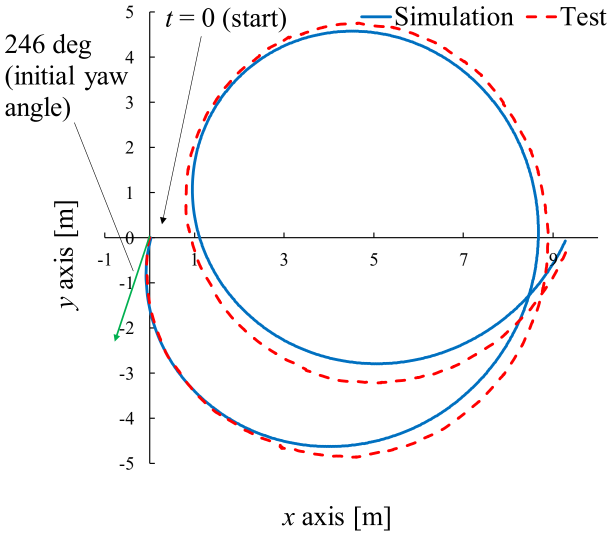

Fig.1 Tractor's trajectory on sloped field

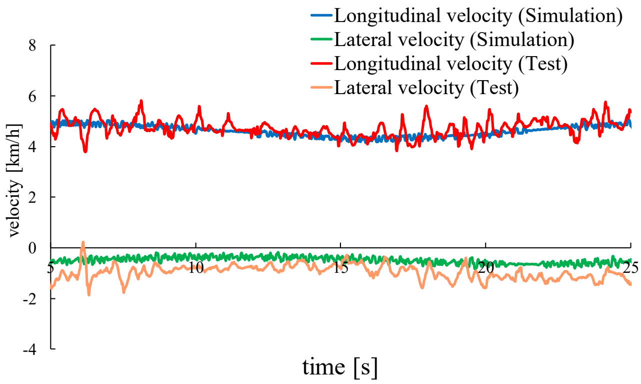

Fig.2 Tractor's velocity (with respect to tractor body frame)

2022 JSAE Congress (Autumn) - Summarized Paper
Issued on October 7, 2022