

Skid Steering Based Maneuvering of Robotic Vehicle with Articulated Suspension

Juyong Kang, Wongun Kim and Kyongsu Yi
Seoul National University

Soungyong Jung
Samsung Techwin, Gyeongsang-do

Copyright © 2009 SAE International

ABSTRACT

This paper describes a driving control algorithm based on skid steering for a Robotic Vehicle with Articulated Suspension (RVAS). The driving control algorithm consists of four parts; speed controller for tracking of the desired speeds, yaw rate controller which computes a yaw moment input to track desired yaw rates, longitudinal tire force distribution which determines an optimal desired longitudinal tire force and wheel torque controller which determines a wheel torque command at each wheel to keep slip ratio at each wheel below a limit value as well as track the desired tire force. Longitudinal and vertical tire force estimators are designed for optimal tire force distribution and wheel slip control. The dynamic model of RVAS for simulation study is validated using vehicle test data. It is found from simulations with closed-loop driver-vehicle-controller system [11] that the proposed driving controller improves maneuverability of RVAS as well as produces satisfactory control performance.

INTRODUCTION

The Robotic Vehicle with Articulated Suspension (RVAS) is being developed to be military purpose with the wide range of applications such as logistics supports, surveillance and light combat operation. In the aspect of mobility, the RVAS benefits from its in-wheel drives and articulated suspensions, which provide the

independent wheel traction control capability and the great improvement of obstacle negotiation ability.



Fig. 1 Robotic Vehicle with Articulated Suspension

In this paper, as part of control algorithm for autonomous vehicle, a driving controller based on a skid steering for a RVAS is investigated. The driving controller consists of four parts; speed controller which computes a total traction force to follow a desired speed, yaw rate controller which computes a total yaw moment input to track a desired yaw rate, tire force distribution and wheel torque controller which determines a wheel torque command of each in-wheel motor.

The total traction force and the yaw moment input, upper level control input, should be applied to RVAS by means of longitudinal tire force distribution and wheel torque controller. Therefore, the objective of tire force distribution is to determine how much traction force is required at each wheel. In this paper, the longitudinal tire force of each wheel is determined in proportion to a vertical tire force of each wheel. From simulation results, it is found that the proposed tire force distribution can prevent unnecessary energy consumption at each wheel. The wheel torque controller based on a sliding mode control computes the wheel torque command so

that a wheel slip ratio does not exceed a slip ratio limit. Finally, the longitudinal and vertical tire force estimator is designed using wheel dynamic and arm dynamic for optimal tire force distribution and wheel slip control. Fig.2 shows a block diagram of the driving controller proposed in this paper.

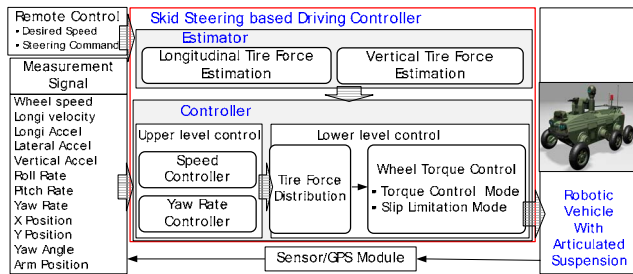


Fig. 2 Driving Controller based on Skid Steering

Closed-loop simulation studies are conducted using human driver model [11] in order to evaluate the control performance of the driving controller. It is found from the simulation results that the driving controller based on a skid steering improves maneuverability of RVAS as well as produces satisfactory control performance.

VEHICLE DYNAMIC MODEL

In this paper, vehicle dynamic model is developed using "MATLAB SIMULINK" in order to analysis dynamic behavior of RAVS and conduct a numerical simulation studies. The vehicle dynamic model consists of three parts as shown in Fig. 3; driving system, arm dynamics and vehicle dynamics. Tire model in the driving system is designed using a Pacejka tire model and is validated by comparison to test data.

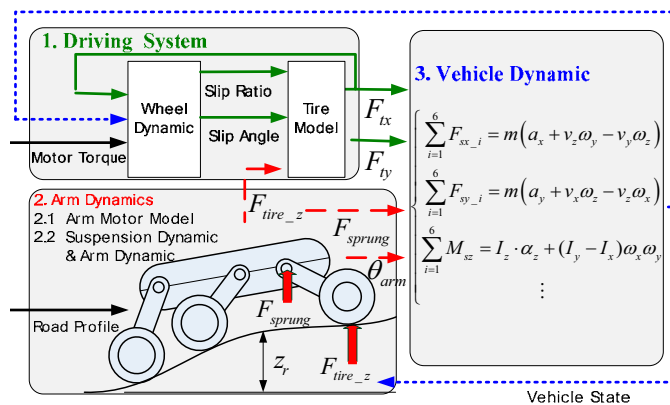


Fig. 3 Vehicle Dynamic Model

Validation of the vehicle dynamic model is accomplished by comparison of simulation predictions to test data of RVAS. For vehicle tests, remote control module as shown in Fig.4 is used to communicate the desired speed and yaw moment input to main controller.

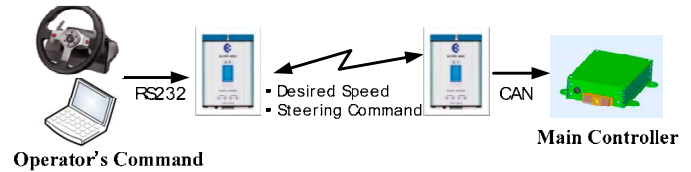


Fig. 4 Remote Control Module

The desired speed and the yaw moment input obtained from vehicle test are applied to the vehicle dynamic model through lower level controller in Fig. 2. Fig. 5 shows a comparison of test data and simulation results.

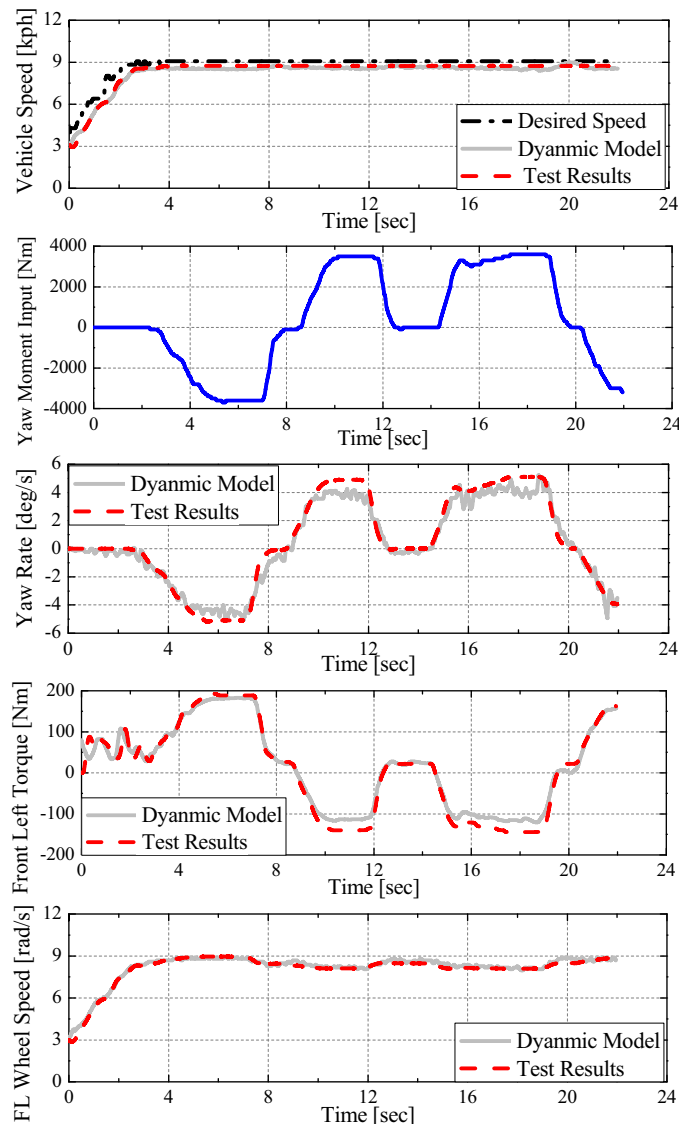


Fig. 5 Comparison of test data and vehicle simulation results

The simulation predictions agree closely with the test data, suggesting that the designed dynamic model is

feasible as a test platform for development of the driving controller.

CONTROLLER DESIGN

Fig. 6 shows a control strategy for driving controller based on a skid steering. An upper level controller computes a total traction force input to follow a desired speed and a yaw moment input to track the desired yaw rate. A desired longitudinal tire force of each wheel is determined using vertical tire force estimation in order to apply the total traction force and the yaw moment input to RVAS. The wheel torque controller is designed to keep a slip ratio below a limit value as well as to track the desired longitudinal tire force.

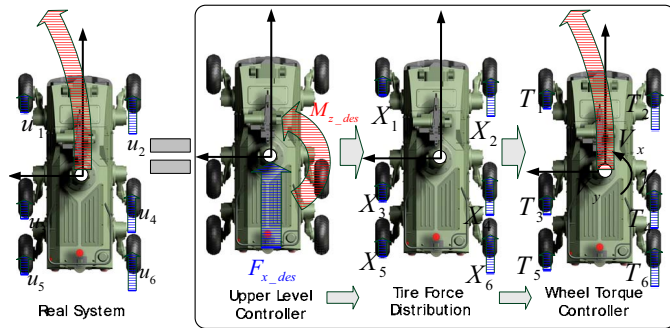


Fig. 6 Control Strategy for Driving Controller based on a Skid Steering

SPEED CONTROLLER – The speed controller in upper level controller is designed to determine a total traction force input. In order to follow the desired speed, the total traction force is computed using PD control method as shown in Fig. 7 and equation (1). [5]

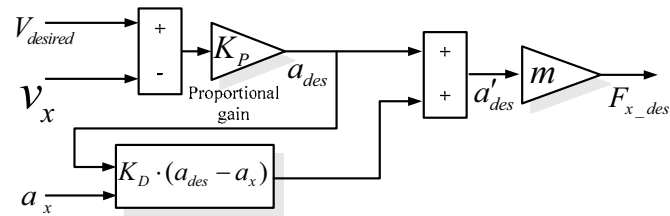


Fig. 7 Speed Controller

$$F_{x_des} = m \cdot [K_p \cdot (V_{desired} - v_x) + K_D \cdot (a_{des} - a_x)] \quad (1)$$

$$a_{des} \cong K_p \cdot (V_{desired} - v_x)$$

where, $V_{desired}$ denotes the desired speed, respectively, a_{des} the desired acceleration, v_x the vehicle speed, a_x the longitudinal acceleration, K_p and K_D the PD control gain.

YAW RATE CONTROLLER – Yaw rate controller computes the yaw moment input (M_{z_des}) for follow the desired yaw rate (γ_{des}). The target yaw rate (γ_t) is determined based on the steering command (δ_{com}) and 2-DOF bicycle model as follows [3]:

$$\gamma_t = \frac{v_x}{L(1 + v_x^2 / V_{ch}^2)} \cdot \frac{\delta_{com}}{K_{SR}} \quad (2)$$

where, V_{ch} denotes characteristic speed of the vehicle and the steering command can be obtained using remote control module. The desired yaw rate is modified to smoothly limit the vehicle yaw rate based on the tire/road condition [9] as follows:

$$\gamma_{des} = \begin{cases} \gamma_t & \text{if } |\gamma_t| < \frac{\mu g}{v_x} \\ \frac{\mu g}{v_x} \text{sign}(\gamma_t) & \text{if } |\gamma_t| \geq \frac{\mu g}{v_x} \end{cases} \quad (3)$$

The yaw moment input is determined using modified bicycle model as shown in Fig.8. Equation (4) shows the dynamic equation of the modified bicycle model in view of skid steering based vehicle.

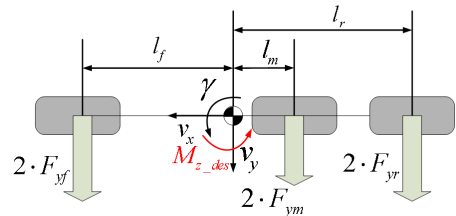


Fig. 8 Modified 2-DOF bicycle model

$$m \cdot (\dot{v}_y + v_x \cdot \gamma) = 2 \cdot F_{yf} + 2 \cdot F_{ym} + 2 \cdot F_{yr} \quad (4)$$

$$I_z \cdot \dot{\gamma} = 2 \cdot l_f \cdot F_{yf} - 2 \cdot l_m \cdot F_{ym} - 2 \cdot l_r \cdot F_{yr} + M_{z_des}$$

Sliding mode control method is used for design of yaw rate controller, and sliding surface is defined using the difference between the desired yaw rate and actual yaw rate as follows:

$$s = \gamma - \gamma_d \quad (5)$$

The control objective is to keep the sliding surface at zero. This can be achieved by choosing the control law such that

$$\frac{1}{2} \frac{d}{dt} s^2 = s \dot{s} < -\eta \cdot |s| \leq -K \cdot |s| \quad (6)$$

where, K and η are a positive constant.

Using Equation (4) and (6), the yaw moment input can be obtained as follows: