Collision Avoidance for Full Four-Wheel Nonlinear Vehicle through Model Predictive Controller

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Abstract

Advanced collision avoidance strategies for detecting obstacle and enforcing aggressive lane changes while braking are still in development to increase driver safety. Our project focuses on designing a full, four-wheel nonlinear car model with advanced control technique using a MATLAB/Simulink numerical simulation environment. The car model undergoes various accident avoidance features and scenarios implemented through a Model Predictive Controller (MPC). The MPC governs the vehicle's driver inputs (braking, steering, throttle) by enforcing constraints and optimizing parameters that successfully allows the car to maneuver around obstacles. By focusing on the steering angle of the front wheels and manipulation of the parameters specific to the controller (prediction horizon, control horizon, and sample time), we established a robust control system able to complete the ultimate task of collision avoidance in various scenarios. Our results conclude that linear model predictions are merely situationally effective, but most of the driving scenarios necessitate the implementation of a nonlinear predictive model. However, with this nonlinear predictive model, computation times are increased to a point where maneuver control sequences can non longer be calculated online and must instead be determined a priori.

Background

- Insurance Institution for Highway Safety (IIHS) states vehicles equipped with collision avoidance systems are involved in fewer accident and injury-related car crashes
- In 2016, National Highway Traffic Safety Administration (NHTSA) declared that starting from 2022, all new vehicles will be equipped with an automatic emergency braking system

Future Direction

- Modify the internal plant model to include a braking force
- Information about the behavior of the vehicle with a control system that exerts a braking force while implementing a lane change
- Conduct experimental validation of the new obstacle avoidance strategy by changing variable values, parameters and constraints

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Materials and Methods

$$1a.\ m\dot{v}_x = mv_y\psi + \sum_{i=1}^{4} F_{xi}\ ,\quad 1b.\ m\dot{v}_y = -mv_x\psi + \sum_{i=1}^{4} F_{yi}$$

$$1c.\ J_z\ddot{\psi} = l_f(F_{y1}+F_{y2}) - l_r(F_{y3}+F_{y4}) + \frac{w_t}{2}(-F_{x1}+F_{x2}-F_{x3}+F_{x4})$$

$$2a.\ F_{xi} = f_{xi}\cos(\delta_i) - f_{yi}\sin(\delta_i) \quad 2b.\ F_{yi} = f_{xi}\sin(\delta_i) - f_{yi}\cos(\delta_i)$$

$$3.\ f_{x1} = f_{x2} = \sigma\frac{F_b}{2} \quad f_{x3} = f_{x4} = (1-\sigma)\frac{F_b}{2} \quad 4.\ f_{yi} = \sqrt{(\mu_i F_{zi})^2 - f_{xi}^2}\ \sin(C_i arc\tan(B_i\alpha_i))$$

$$5a.\ \alpha_1 = \frac{v_y + l_f\dot{\psi}}{v_x - \frac{w_t}{2}\dot{\psi}} - \delta,\quad \alpha_2 = \frac{v_y + l_f\dot{\psi}}{v_x + \frac{w_t}{2}\dot{\psi}} - \delta$$

$$\alpha_3 = \frac{v_y - l_r\dot{\psi}}{v_x - \frac{w_t}{2}\dot{\psi}},\quad \alpha_4 = \frac{v_y - l_r\dot{\psi}}{v_x + \frac{w_t}{2}\dot{\psi}}$$

Symbol	Vehicle Parameters	Values
J(kgm2)	Yaw Inertia	3344
B1,2	Front Tire Parameter	-10.5
B3,4	Rear Tire Parameter	-12.7
C1,2,3,4	Tire Parameter	0.5
σ	Weight Distribution	0.7
μ	Friction Coefficient	1.0
δ(°/rad)	Steering Angle	
α(°/rad)	Slip Angle	

Figure 1. Top Vehicle Dynamic Equations derived from Newton's second Law. Equation 1 represents the vehicle state of motion. Equation 2 represents the forces components on the tires of the vehicle in the lateral and longitudinal direction. Equation 3 represents the braking force. Equation 4 represents simplified Pacejka Tire model. Equation 5 represents the tire slip angle
Figure 1. Right Table of vehicle parameters

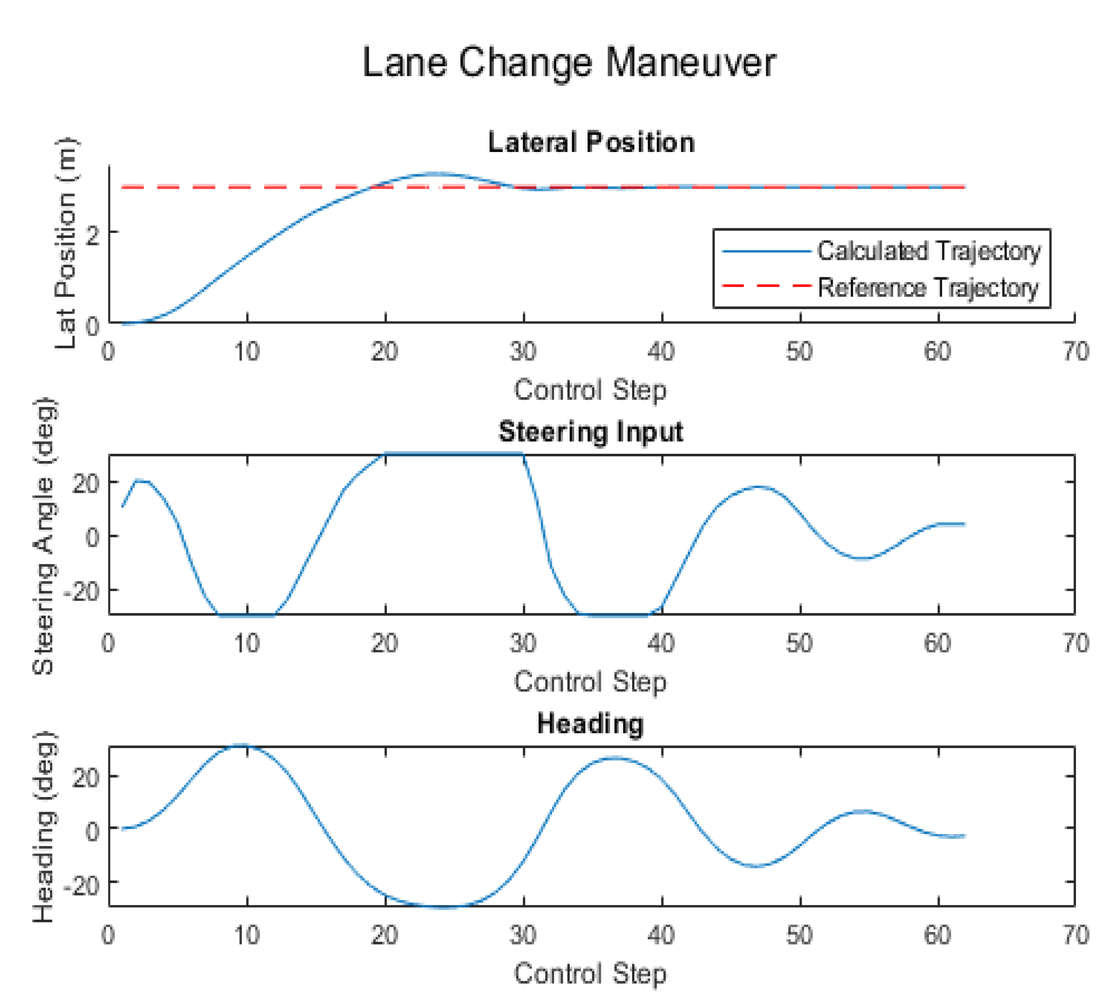

Figure 4 Top: Rate-constrained control sequence. Sample time T_s is 0.1 seconds yielding sampling frequency of 10Hz. So, control step 40 is 4 seconds into simulation.

Conclusion

In conclusion, the vehicle control system was able to successful detect an obstacle and communicate with the MPC to implement a lane change. The Nonlinear MPC control captured the vehicle's movement and able to provide an close enough control sequence estimates.

Results

$$J = \sum u_i^2 + K_\psi \psi_i^2$$

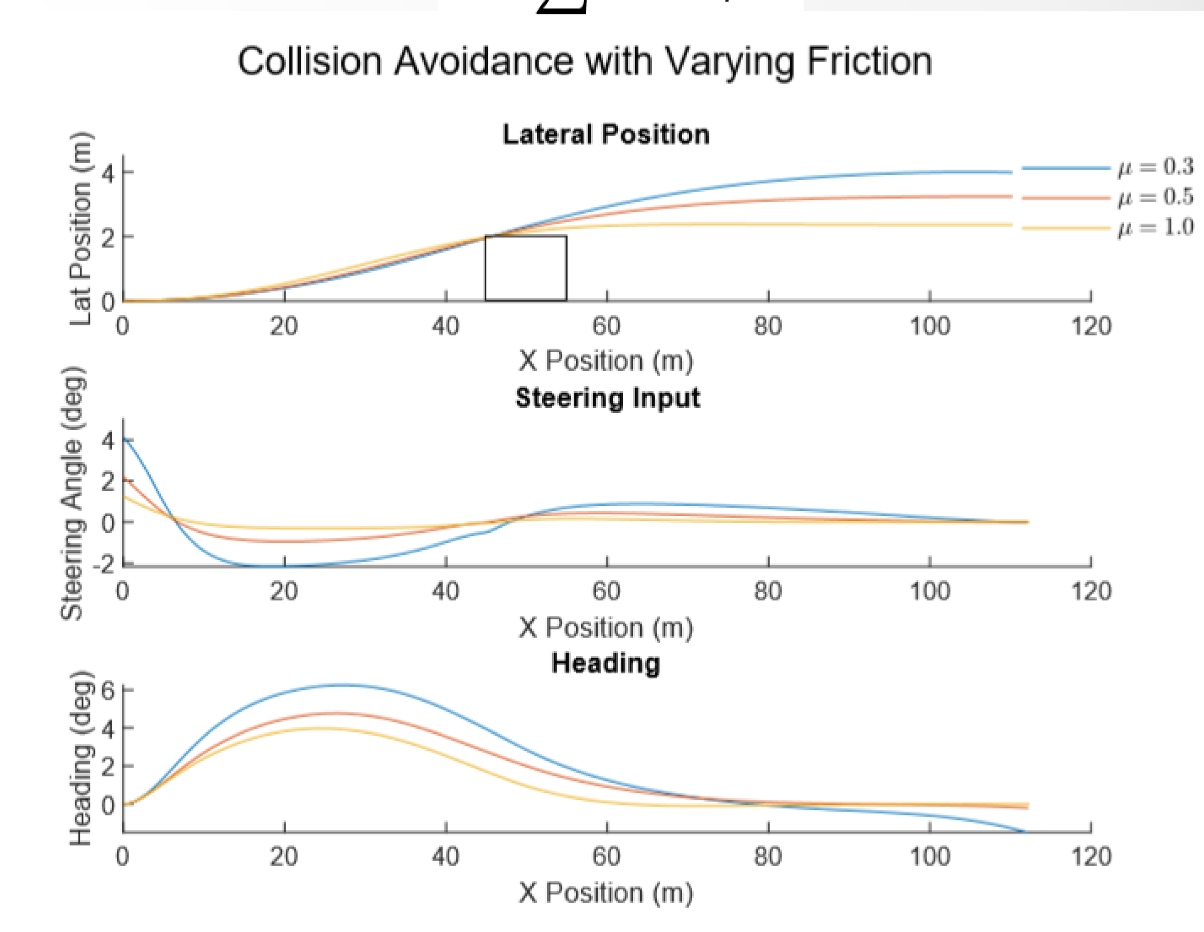

Figure 3 Top: Generalizing Objective function to control input i.e. minimize wheel deflection such that avoidance yields highest maneuvering efficiency. Emphasis on constraints where 4m lateral position is road boundary and obstacle width is 2 m.

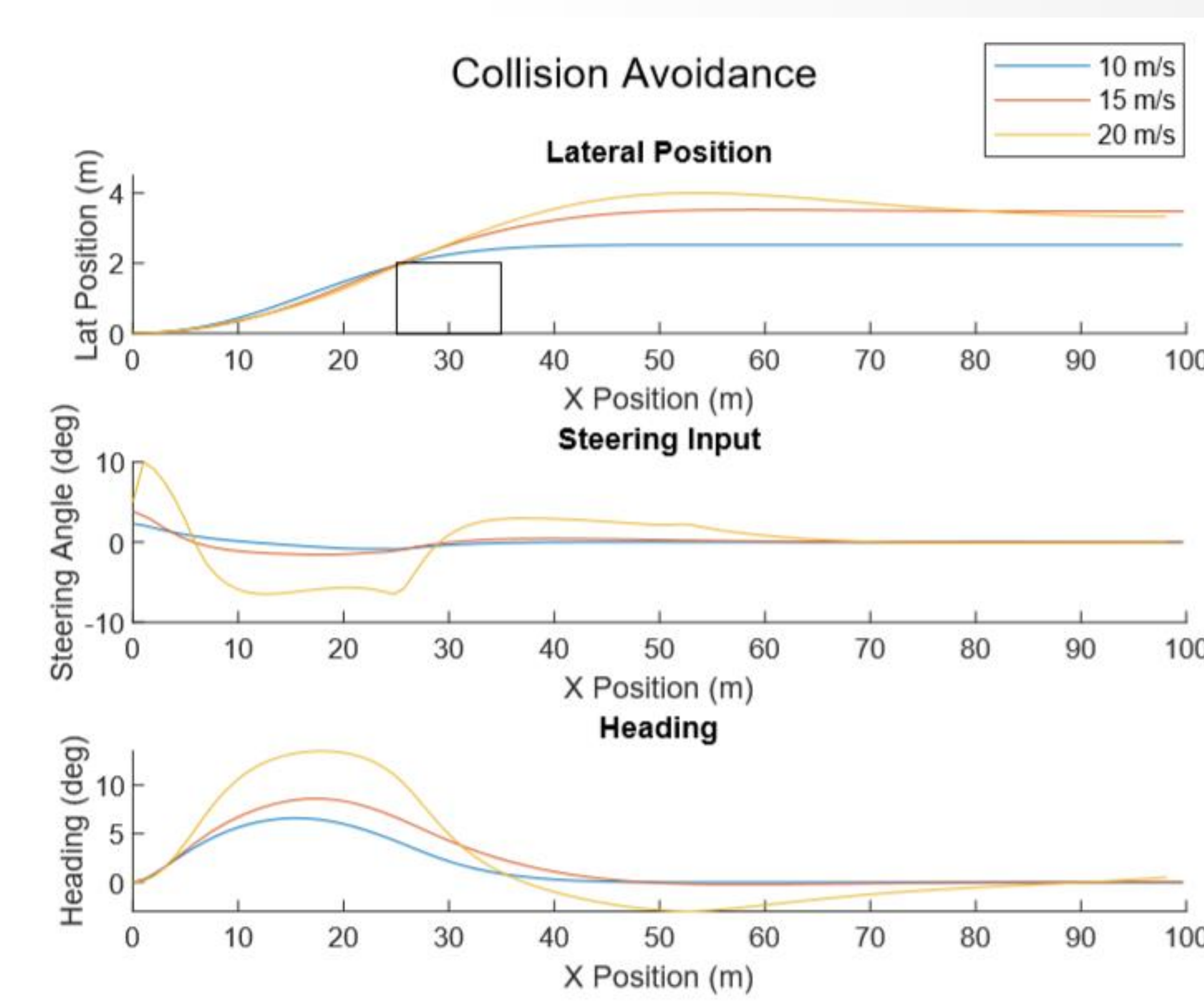

Figure 3 Top: Demonstration of control algorithm robustness through successful collision avoidance at speeds ranging from 10 m/s (22 mph) to 20 m/s (44mph).

References

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