Improve CAVs Safety by Proper Vehicle Longitudinal Speed Planning with the Preview of Path Friction and Curvature*

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***Abstract*— The improvemtns in vechile safety can be achieved by limiting the vehicle speed based on the road condition. In this paper, we at fisrt introduce an idea of road friction preview through CAV. Then we present an algorithm to generate a longitudinal vehicle velocity limit profile based on the desired path curvature and the preview of path friction. Moreover, the preview distance is discussed to ensure the vehicle has sufficient time to take action for upcoming hazardous situations. Finally, the efficiency of work is demonstrated through an application case where a vehicle with a simple driving controller can follow the path well with the preview of velocity.**

I. Introduction

The traffic accident is fatal and has a huge negative influence on economic costs. [follow some data from reference] Many factors attribute to safety, but a large part of the accidents are caused by slick roads (snow, ice, raining, etc.) and overspeeding.

One way to make cars safer is the development of the ADASs (Advanced Driver Assistance Systems) such as EBS, LKA, and ESC, etc., which can assist the drive to follow the desired path stably in hazardous situations. [follow with summary and examples of ADAS contollers]

However, many of the controllers are activated only when the vehicle states are out of stability. For example, the driver may take an emergency brake when entering into a slick road or a split friction road. [follow with more examples and summary]. The controller has a stable region. Consequently, the controller even fails to keep the vehicle stable if the road condition changes intensively. [ref]

(Different from the reaction controller, researchers developed the proactive envelope controller with real-time road friction estimation, which can keep the vehicle within a stable region. But it still can not prevent the vehicle from veering away from the desired path when the road condition changes intensively.)

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Existing research has shown that appropriate longitudinal velocity planning is vital when following a path with tight curvature change [1]. The idea is to reduce vehicle speed before a potentially dangerous situation is reached, in contrast with widely used stability control systems that only react once loos of control is imminent.

(need a better transition)However, they only consider the variation of curvature, and little attention has been paid to the road surface friction condition changing when conducting longitudinal velocity planning. For example, if the vehicle can preview the path friction reduction and slow down appropriately before entering the slick region, then even not need a complicated algorithm to stably. The prior estimation of friction and peak tire force, before the slick region is reached, allows a vehicle chassis control system to work more reliably and proactively [2]. In this way, even a simple steering control algorithm can follow the path well.

Fortunately, a potential solution to preview the road surface friction condition can be motivated by the increasing research into Connected and Autonomous Vehicles (CAV). This solution takes advantage of the information sharing between networks including vehicle-to-vehicle, vehicle-to-infrastructure, and vehicle-to-cloud-database systems. In this network, each vehicle and roadside unit can measure local road friction and share it with the cloud database. Each vehicle can query the aggregated information from the network database. A demo framework of this is shown in Fig. 1.

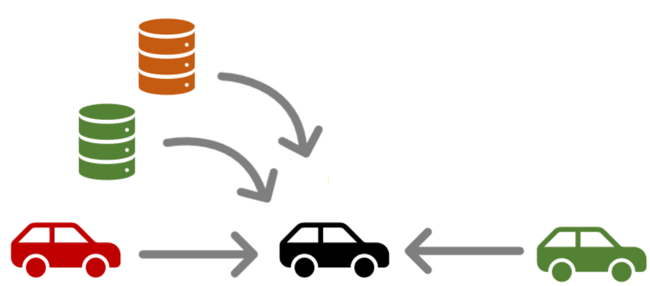

Figure 1. A strategy of road friction preview with a roadside shared roadway database. (need a better diagram to show the data sharing idea and more words to describe it)

The improvemtns in vechile safety can be achieved by limiting the vehicle speed based on the road condition. In this pa[illegible]ve introduce an idea of road friction preview through C[illegible]hen we present an algorithm to generate a longitudinal vehicle velocity limit profile with the desired path curvature and the preview of path fri Moreover, the preview distance is discussed to ensur ehicle has sufficient time to take action for upcoming hazardous situations.

The remainder of this paper is organized as follows: Section II discusses the velocity limit profile planning based on the tire limits. Section III analyzes the preview distance. Section IV shows an application case. Finally, a conclusion section summarizes the main results of the work.

II. Vehicle Longitudinal Velocity P ing Given a Reference Path

This section presents the generation of minimum-time speed profile which vehicles can achieve without exceeding available road friction/vehicle handing limits [3]. At first, the approach to describe the path by s and κ is introduced and then followed by a detailed velocity planning method.

A. Introduction of GG diagram or Tire friction limits(maybe)

The shape of g-g diagram or friction circle depends on the road friction. Vehicle acceleration has it.

Fig. 2 shows the tire force on different road conditions and the corresponding g-g diagram.

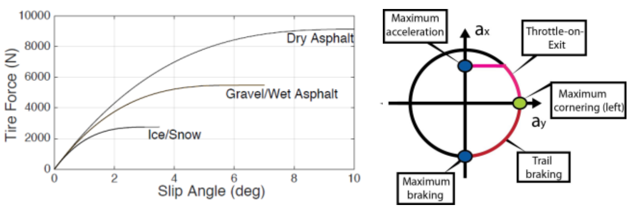

Figure 2. A plot of 0.9g and 0.2g friction circle()

A. Path Representation

The use of clothoid for general vehicle path planning is not uncommon. Refer to [4] Minimum curvature [5] and optimal time.

Fig. 3 shows a sample curvy path.

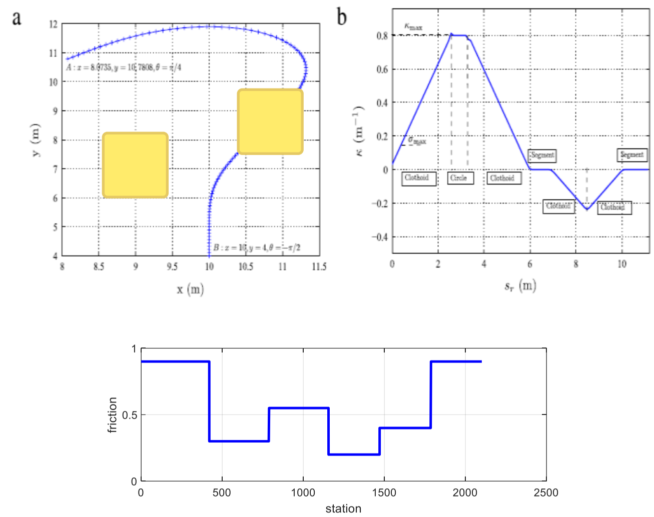

Figure 3. A smaple path with friction varitation

In real-world, the grade of the path also has a significant influence on the vehicle acceleration and deceleration behavior. We may need to include the grade term.

B. Velocity Profile Generation

Velocity planning has a significant impact on driving safety, especially when vehicles drive on a road with changing friction and geometry. In this paper, velocity generation is performed by considering the tire friction limits constraints. The approach presented in this paper is inspired by those work three passes [3], nonlinear optimization [1], segment and iteration [6], where a velocity profile is planned given the path curvature.

For a single mass vehicle model:

[equations]

Add an adjusting parameter to the friction limit to compensate for the friction estimation uncertainty or just for the conservation consideration. In this way, the friction circle can be represented by a relationship between and as follows:

[equations]

The first step is to generate the speed profile is to find the maximum permissible steady state vehicle velocity with zero longitudinal acceleration. If ignore the load transfer and road grade, this is given by (1):

$$U_x(s) = \sqrt{\mu(s)g/\kappa(s)} \tag{1}$$

Finally, the longitudinal acceleration is:

$$\frac{dU_x(s)}{ds} = \pm \frac{1}{U_x(s)}\left(\sqrt{\left(\lambda\mu(s)g\right)^2 - \left(\kappa(s)U_x^2(s)\right)^2} + g\sin(\theta)\right) \quad (2)$$

where: λ is an adjusting parameter

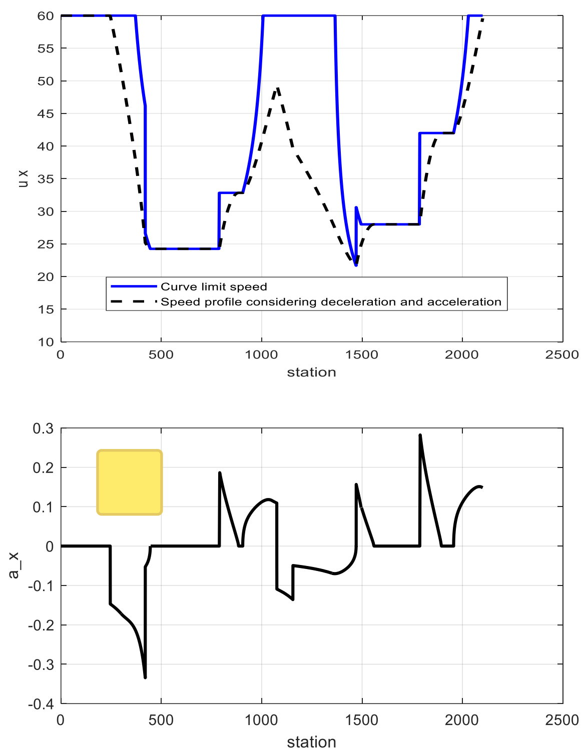

Figure 4. A a sample of velocity profile and the acceleration

In (2), λ can be chosen as a value smaller than 1 for some speed conservation.

III. Preview Distance

In this section, we discuss the friction preview distance, which indicates how much friction data a vehicle needs to query from a database so that it can have sufficient time to take action for any upcoming situation.

Strategy can be: find the most critical scenario.

A. *Minimum Preview Distance given the Vehicle Current States*

The worst case is entering a circle, with a sudden friction decrease.

The minimum curvature can be obtained from the path, and the minimum ion can be assumed to be 0.1 for conservation.

The distance is a function of Ux, ax, max(κ), min (μ)

$$d_{prev} = U_x \tau - 0.5 a_{x,\min} \tau^2 + const \quad (3)$$

Case discussion:

B. *Speed Profile Depneds o review Distance*

The vehicle needs to move slower if with less visibility.

Both road condition and preview distance has an influence to the vehicle speed profile.

IV. Experiment and Application Case

A vehicle with rear driving, front steering, under steering, or oversteering.

A path with a length of 5 km, compare the velocity results with and without the preview of friction.

A simple driver controller can follow the path well with the preview of friction.

A controller behavior with limited friction preview distance.

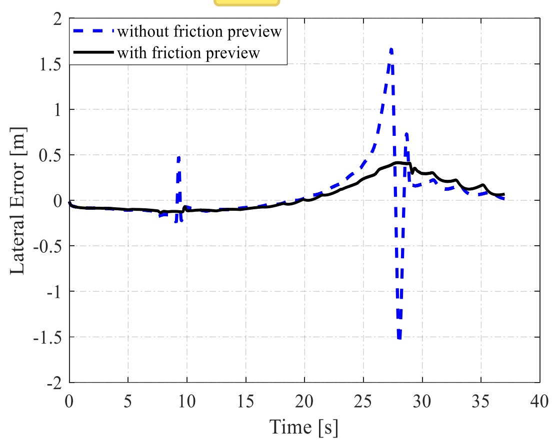

Figure 5. An apllication of preview

V. Conclusion

In this paper, we ... . The idea behind this xtend individual intelligence with network intelligence.

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