Design and evaluation of an Adaptive Lane Keeping System

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Abstract

The lane keeping system (LKS) is a key technique to Autonomous vehicles and plays an important role in staying safety. The lane keeping system (LKS) includes lane detection, lane tracking, and control that helps the driver keeping in maintaining safe travel within the marked lane of the road when the vehicle begins to move out of its lane. The lane keeping system can reduce the risk of lane departure effetely. This study presents the design and evaluation of lane keeping system (LKS). All simulation of the controller and the plant in this study was based on the developed model in SIMULINK environment. The system was built for a camera-based lane sensing system and steering wheel actuator. The control model uses the algorithm that combines data processing from lane keeping controller from the Model Predictive Control Toolbox and simulates in performance of the closed loop system.

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Introduction

In recent years, the total of traffic accidents has been increasing due to the increasing number of cars. Driving safety issues have become a major concern in the automotive sector. Unintended lane departures account for a high percentage of road accidents in general and especially severe accidents [1]. Hence, to improve driving safety and reduce driver's driving burden, Lane Keep System (LKS) has been extensively studied and gradually applied. As a typical type of advanced driving assistance system, lane-keeping assistance systems aims to prevent unintended lane departures, so they are also called lane departure prevention (LDP) systems [2]. The lane keeping system (LKS) can actively control the vehicle steering to help the driver keep the car within the lane to reduce the risk of lane departure effetely. This system uses a front-view camera to acquire roadway images to recognize lane markings through a series of image processing processes for obtaining road features and the position relation between the vehicle and its lane [3].

The ego vehicle determines the lane boundaries and the angle of curves in front of its lane. To idealize the LKS system, the previewed curvature, the lateral deviation, and relative yaw angle between the centerline of the lane and the ego vehicle are mostly relied on [4]. When the data from lane detections is inaccurate, the model built in this study presents a robust approach to the controller design. The model simulates the impairments introduced by a wide-angle monocular vision camera by using data from a synthetic lane detector. When the data from the sensor is invalid or outside a range, the controller makes decisions. Therefore, this model can provide a safety guard, when the measurement is incorrect, because of the condition in the environment, such as a sharp curve on the road. The model in this study is built in Simulink and using the model predictive control (MPC)

System Overview

Open Loop V.S Closed Loop

The key difference between open loop control system and close loop control system is feedback. An open loop control system only affected by the basis of input; the output has no effect on the control action. A close loop control system as known as feedback control system looks at the output and the alters it to desired condition; the action in system is based on the output. Which means closed loop system makes system more stable and has ability to self-correct while the open loop does not. Therefore, this study using to close loop system with lane sensor data feedback and predictive control system to build the model.

Lane keeping system with the model predictive control (MPC)

There are some common control techniques: proportional integral derivative Control (PID), Linear Quadratic Regulator Control (LQR), Model predictive Control (MPC), and Fuzzy Logic Control (FLC). An advanced control method, MPC has been widely used and in a wide variety of applications in process control systems [6]. Primary advantage of model predictive control (MPC) is its ability to deal with the constraints, which PID controller does not have. Model predictive control numerically solving the optimization problem at each time step and recording horizon approach. Model predictive control can be easily formulated for a complex system, handle constraints and be applicable to linear or non-linear models. In this study, the Model Predictive Control (MPC) is used to build the lane keeping system. The following figure shows model predictive control (MPC) structure.

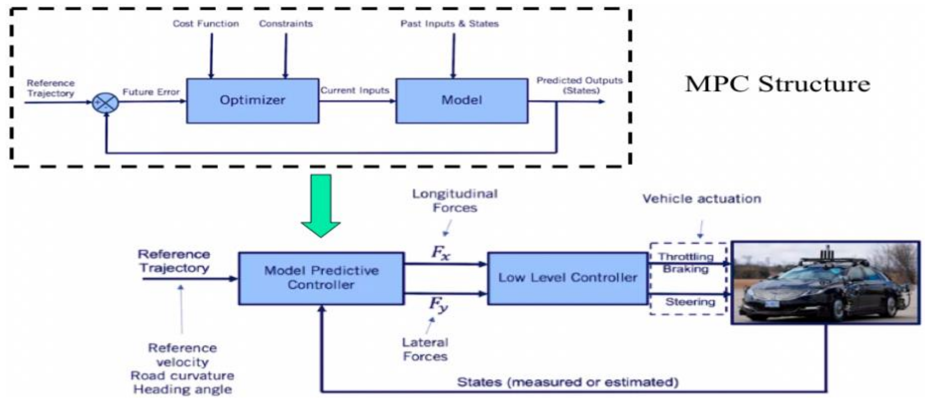

Fig 1. model predictive control (MPC) structure

The following figure shows the detailed architecture of the control.

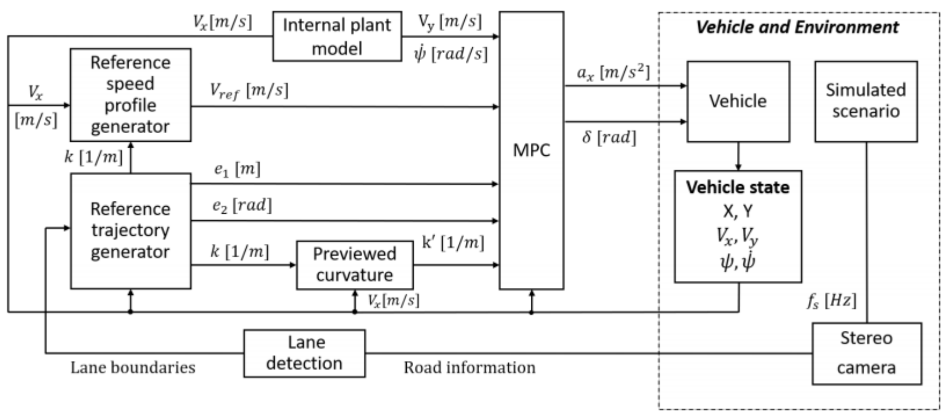

Fig 2. Detailed architecture of the control

Vehicle Dynamics

The vehicle model is based on the linearized single-track model, or bicycle model.

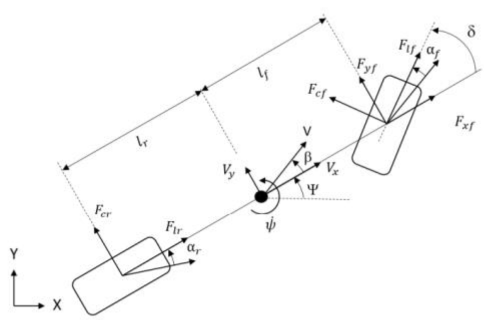

Fig 3. Schematic of the bicycle vehicle model.

linearized vehicle dynamics are given as follows

$$\dot{\beta} = -\frac{C_r + C_f}{mV_x}\beta + \left(-1 + \frac{\ell_R C_r - \ell_F C_f}{mV_x^2}\right) r + \frac{C_f}{mV_x}\delta,$$
$$\dot{r} = \frac{\ell_R C_r - \ell_F C_f}{I_z}\beta + \left(-\frac{\ell_R^2 C_r + \ell_F^2 C_f}{I_z V_x}\right) r + \frac{\ell_F C_f}{I_z}\delta,$$
$$\dot{\psi} = r, \tag{1}$$

where β [rad] is the vehicle sideslip angle, r [rad/sec] is the vehicle yaw rate, ψ [rad] is the vehicle yaw angle, Vx [m/sec] is the longitudinal of the velocity of the vehicle center of mass expressed in the vehicle frame, m [kg] is the total vehicle mass, and Iz [kg m2] is the yaw moment of inertia of the vehicle. In addition, ℓF [m] and ℓR [m] are the longitudinal distances of the vehicle mass center from the front and rear axles, respectively, and Cf [N/rad] and Cr [N/rad] are the cornering stiffnesses of the front and rear tires.

An ego vehicle that has a lane-keeping system must have a sensor, such as a camera. The sensor measures the relative yaw angle and lateral deviation between the centerline of a lane and the ego car and measures the current lane curvature and curvature derivative. The lane keeping system adjusts the front steering angle of the ego car to keep the ego car traveling along the centerline of the lanes on the road. The goal for lane keeping control is to minimize both lateral deviation and relative yaw angle.

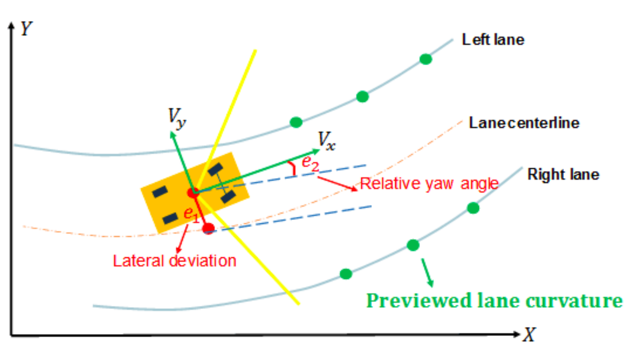

Fig 4. Bicycle model in terms of lateral deviation and relative yaw angle

$$\dot{e_1} = V_x e_2 + V_y \quad (2)$$

$$e_2 = \Psi - \Psi_{des} \quad (3)$$

The desired yaw angle rate is given by:

$$\dot{\Psi}_{des} = V_x \kappa \quad (4)$$

Where, κ denotes the road curvature.

The state-space model for lateral dynamics can be obtained by linearizing the bicycle model [5].

$x^{\cdot}$ = Ax + Bu is represented as:

$$\begin{bmatrix} \dot{y} \\ \ddot{y} \\ \dot{\Psi} \\ \ddot{\Psi} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & -\frac{2C_{\alpha f}+2C_{\alpha r}}{mV_x} & 0 & -V_x - \frac{2C_{\alpha f}L_f - 2C_{\alpha r}L_r}{mV_x} \\ 0 & 0 & 0 & 1 \\ 0 & -\frac{2L_f C_{\alpha f} - 2L_r C_{\alpha r}}{I_z V_x} & 0 & -\frac{2{L_f}^2 C_{\alpha f} + 2{L_r}^2 C_{\alpha r}}{I_z V_x} \end{bmatrix} \begin{bmatrix} y \\ \dot{y} \\ \Psi \\ \dot{\Psi} \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{2C_{\alpha f}}{m} \\ 0 \\ \frac{2L_f C_{\alpha f}}{I_z} \end{bmatrix} \delta \quad (5)$$

The following figure shows the vehicle dynamic built in Simulink.

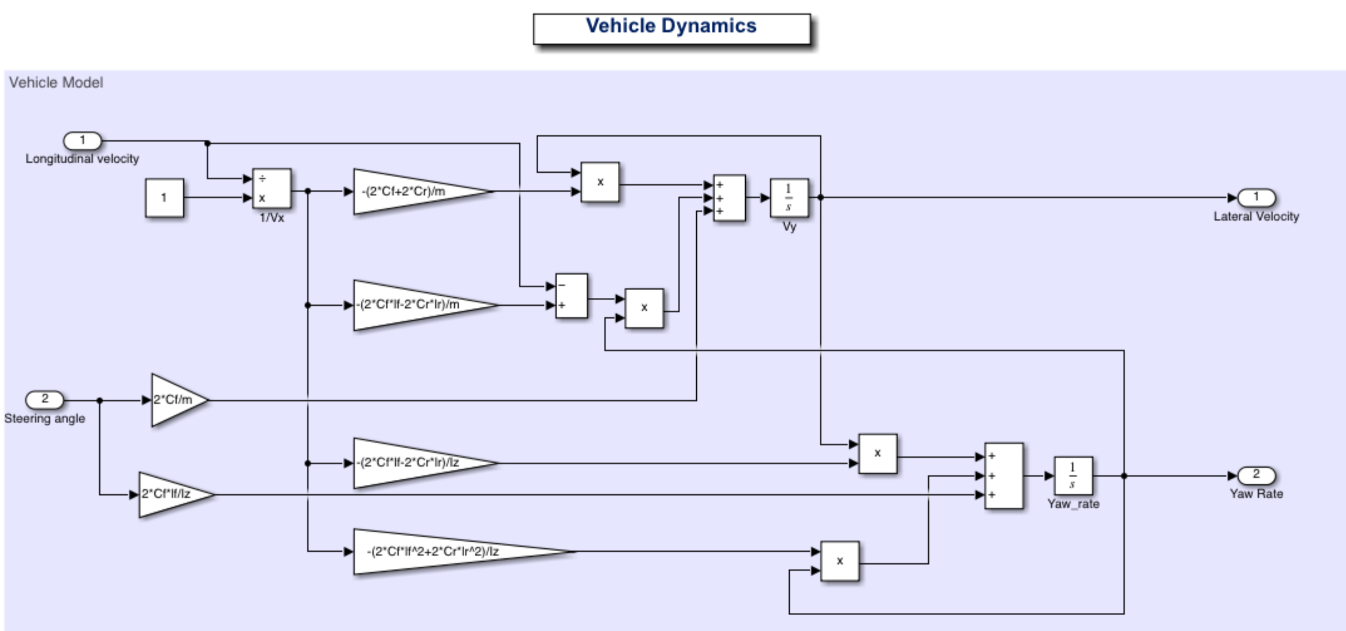

Fig 5. Vehicle Dynamics model

The following figure shows the lane keeping controller using the model predictive control (MPC).

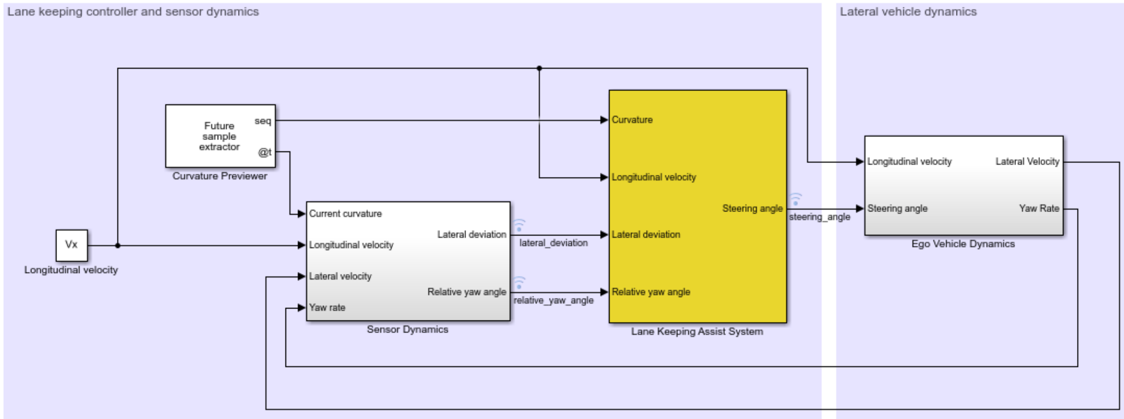

Fig 6. Lane Keeping controller and sensor dynamics model

<u>Lane keeping system with lane detection</u>

The Lane keeping system with lane detection model contains two main parts: Lane Keeping Assist System, and Vehicle and Environment (see the following figure).

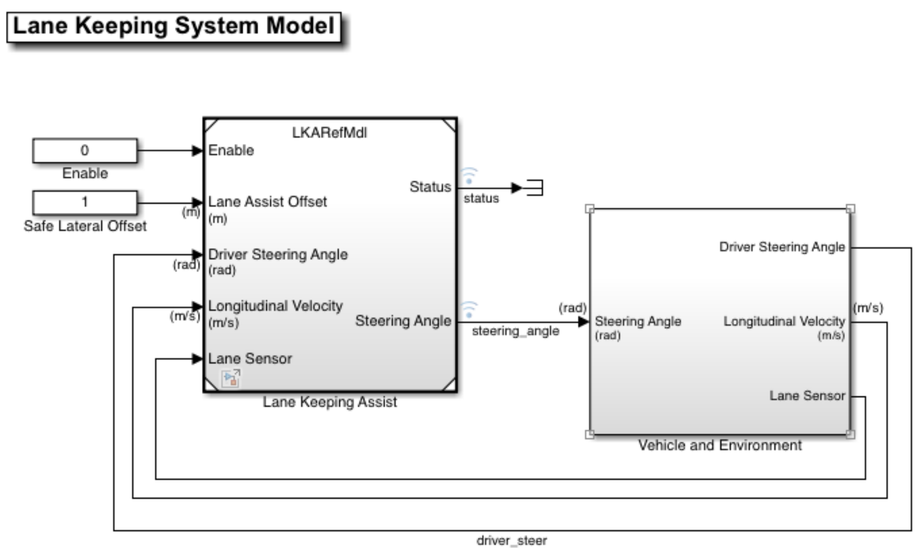

Fig 7. Lane Keeping System Model in SIMULINK

The Lane Keeping Assist System controls the front steering angle of the vehicle. This model contains four main parts: Estimate Lane Center, Lane Keeping Controller, Detect Lane Departure, and Apply Assist (see the following figure).

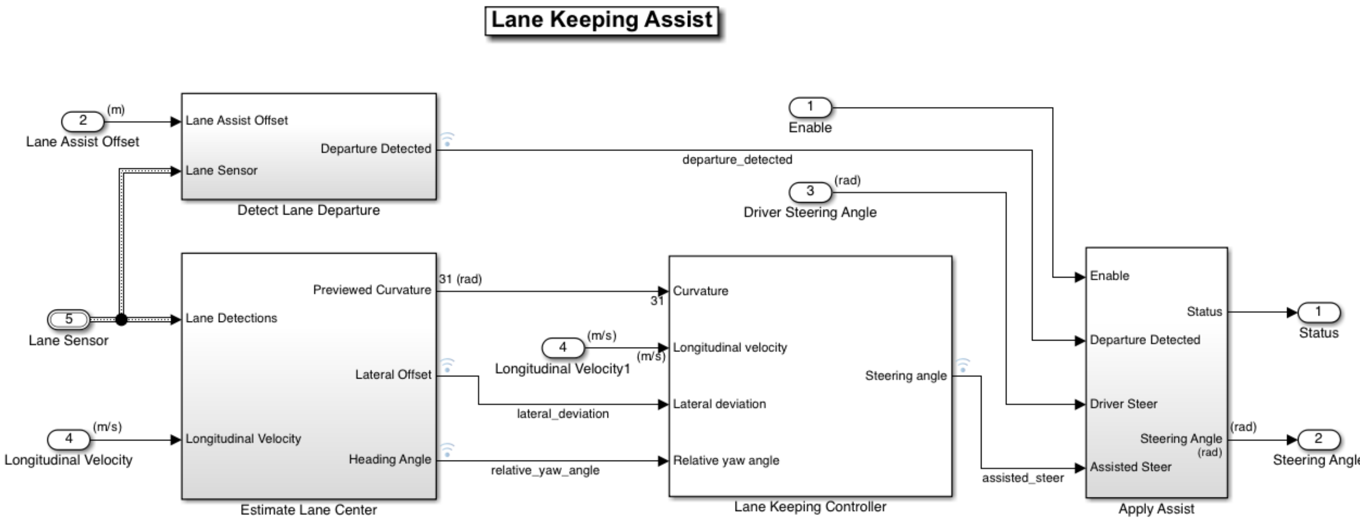

Fig 8. Lane Keeping Assist Model

The Apply Assist subsystem decides who is going to take control of the ego vehicle, the driver or the lane keeping controller. When the lane departure is detected, it will switch to assisted steering. Moreover, when the driver begins steering within the lane again, it will switch the control back to the driver.

The goal for the Lane Keeping Controller block is to keep the vehicle in its lane and follow the curved road by controlling the front steering angle. To achieve this goal, the lateral deviation and the relative yaw angle should be close to zero. This controller calculates a steering angle for the ego vehicle based on the following inputs: Previewed lane curvature, Ego vehicle longitudinal velocity, Lateral deviation, and Relative yaw angle.

Detect Lane Departure subsystem (see the following figure) will detect if lane departure its lane. If departure being detected, and the system will send the signal to the controller, the control will switch to lane keeping system to driver the ego vehicle.

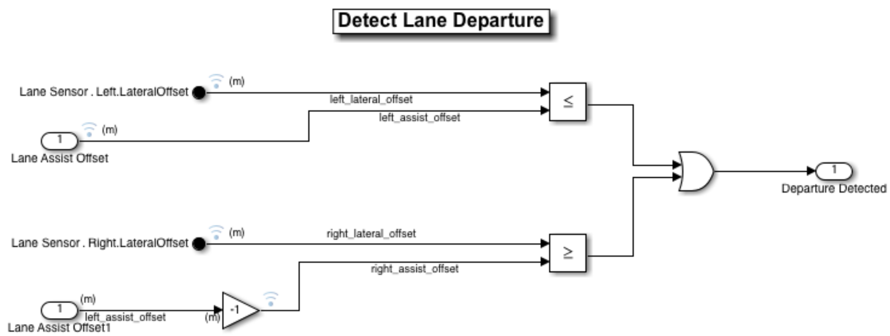

Fig 9. Detect Lane Departure Model

Vehicle and Environment subsystem (see the following figure) models the motion of the ego vehicle and the environment. This project used the Driving Scenario Designer in Simulink to create the environment and vehicle.

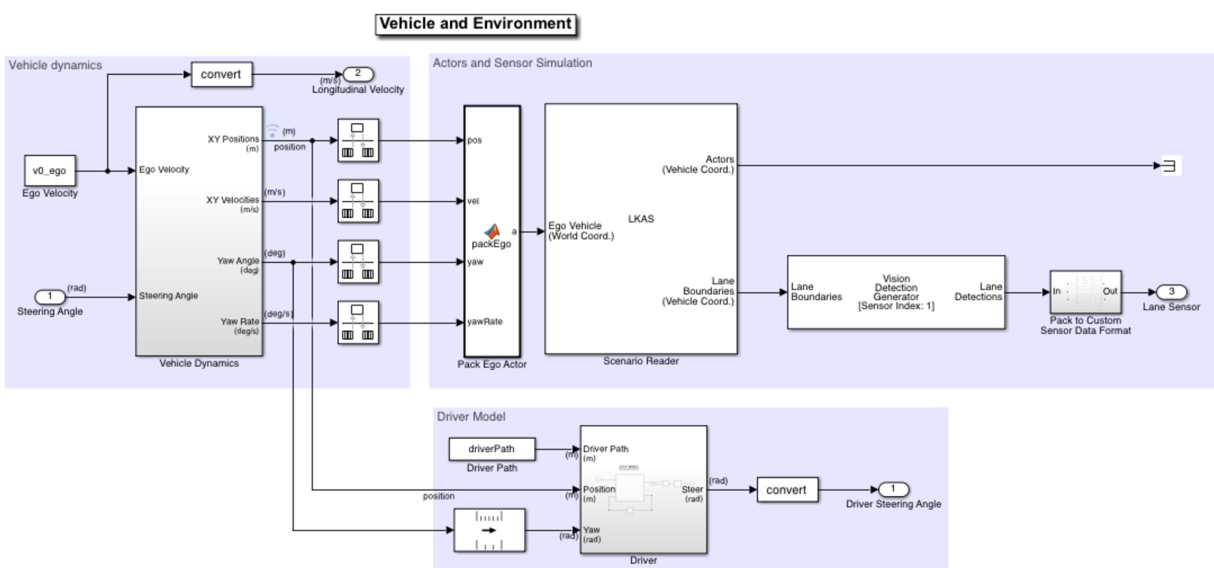

Fig 10. Vehicle and Environment Model

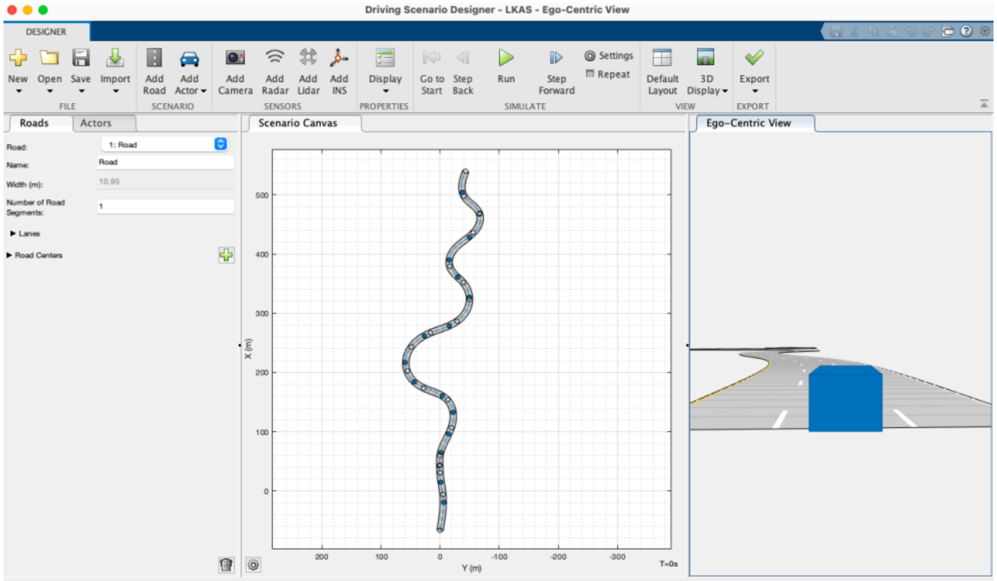

Fig 11. Driving Scenario Designer Model

Simulations Results and Discussion

<u>Stability of close loop system</u>

As shown on the root locus, the gain values can vary from zero to infinity without passing the imaginary axis, and the poles of the transfer function are in the left side of the S-plane, thus the system is stable. Besides since the poles of the open loop are not close the imaginary axis the system should not be oscillatory.

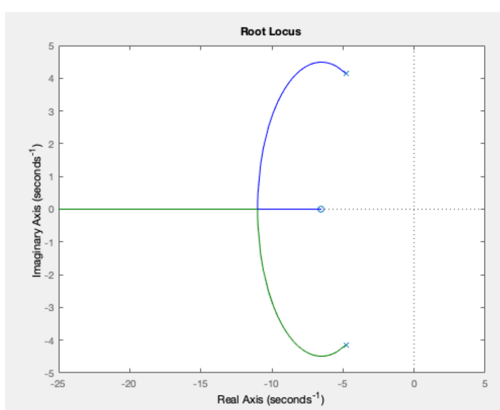

Fig 12. Loot Locus Plot for controller

Simulation for lane keeping system with the model predictive control (MPC).

The lateral deviation and the relative yaw angle both converge to zero. Therefore, the ego car follows the road closely based on the previewed curvature.

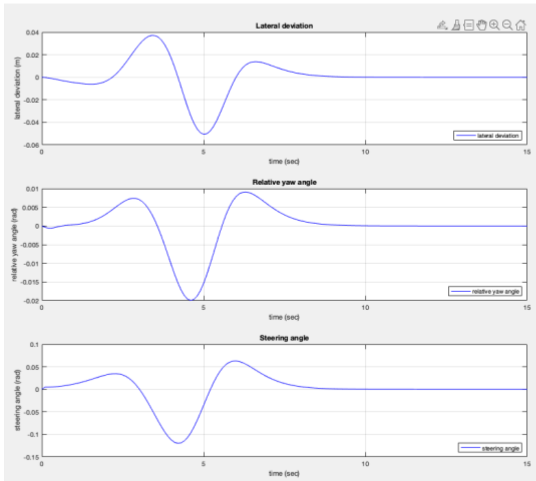

Fig 13. Lateral deviation and the relative yaw angle

Simulation for lane keeping system with lane detection

To simulate and plot the result, use the Bird's-Eye Scope. The Bird's-Eye Scope shows a symbolic representation of the road from the perspective of the ego vehicle.

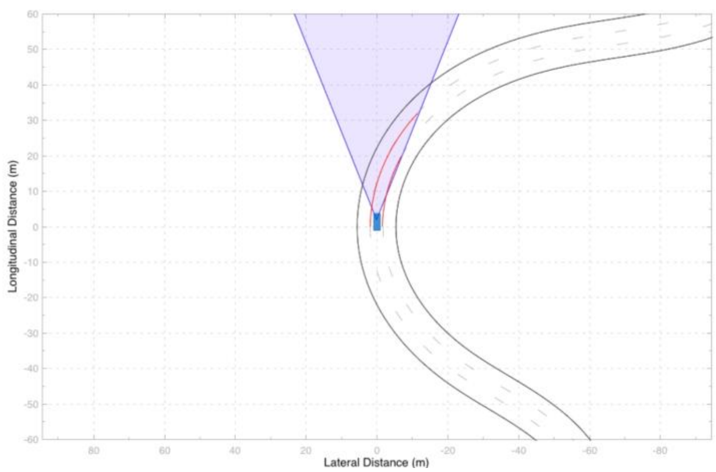

Fig 14. Simulation Using the Bird's-Eye Scope

The blue curve (see the following figure) is the driver path shows that the distracted driver may drive the ego vehicle to another lane. The red curve is the driver with Lane Keeping System shows that the ego vehicle remains in its lane when the road curvature changes.

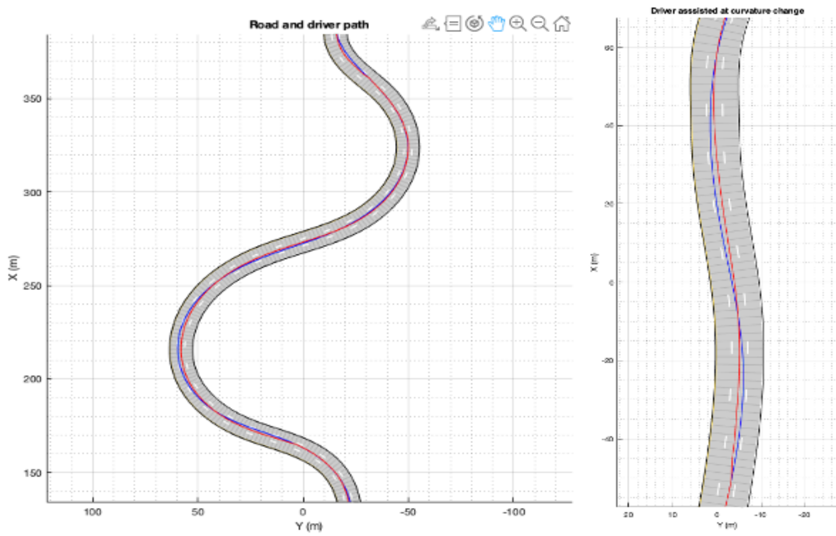

Fig 15. Road and Driver Path

The figure below shows the left and right lane offset. Around 2s, 18s, 40 s, and 50s the lateral offset is within the distance set by the lane keeping assist. The lane departure is detected when this happens.

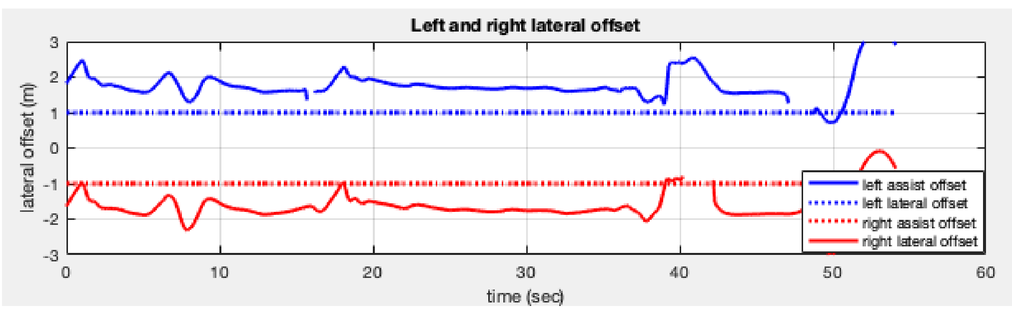

Fig 16. Left and Right Lateral Offset

The figure below shows the LKS status and the detection of lane departure. The departure detected status is consistent with the previous figure. The LKS is turned on when the lane departure is detected, however when the driver can steer the ego vehicle correctly the control is returned to the driver.

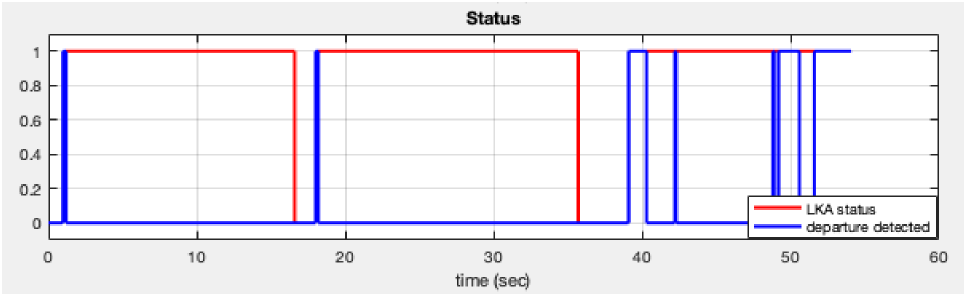

Fig 17. Lane Keeping System Status and Departure Detect

The figure below shows the steering angle from driver and LKS. When the difference between the steering angle from driver and LKA is small, the LKS releases control to driver.

Fig 18. Driver and Assisted Steering Angle

Conclusion

This project has successfully developed and simulated the Lane Keeping System (LKS) using the Model Predictive Control, and this system has been validated through software simulation on the SIMULINK environment. The simulation results show that this system can keep the vehicle driven within the marked lane of the road and prevent the driver effetely from road accidents caused by the unintentional lane departure. In the next few years, the developed lane keeping system will be sufficiently capable of being used worldwide by the improvement of the reliability and stability of the system.

References

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