The Steering Actuator System to Improve Driving of Autonomous Vehicles based on Multi-Sensor Data Fusion

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Abstract

In autonomous vehicles, the control unit must be based on two main goals, first maintains the stability of the car second follows the desired path. All things considered, the controller's effectiveness is heavily dependent on the details of the steering system actuators. The necessary steering is set by a higher-order controller. The time delay of the steering actuator is one of the main features affecting the performance of the controller. While the artificial intelligence and artificial ethic are new apparatuses in autonomous vehicles but their ICs and electrical component are exposed to fusion. This paper primarily presents a more reliable system work during the fusion of multi-sensor information. We design the requirements of the steering system and the sureness of stability control in autonomous vehicles, also finding the suitable parameters for high-level control algorithms to compensate for time delay and ensure vehicle stability. The vehicle's steering angle response was obtained by testing the actuator of electric power steering (EPS) undergoing different speeds. In fact, using the identification of the system has been beneficial because obtaining the transfer function is easier than the actual methods which need the implementation of a mathematical model of the system. The system response of the Input-output has been defined via MATLAB. Full vehicle model simulation results indicate that the found adjustment parameter improves lane-tracking performance in a basic architecture by reducing oscillation and lateral error relative to other instances. The simplified steering system is the primary improvement brought by this effort.

Keywords: Autonomous Vehicles; electric power steering; artificial intelligent; Flexible Manufacturing System (FMS); Information Fusion; multi-sensor information; fusion method.

1. Introduction

In recent years, intelligent automotive technology had a rapid development [1]. The traffic lights, modern intersections, and brake lights having lights on at night makes it easier for vehicles to cross the street securely. In the near future, it will be possible to suggest advanced autonomous cars. Nowadays the question is: How the sensor devices will be designed to make cars driven by computers, not by humans [2]? Intelligent autonomous vehicles consider many advantages (more efficiency, better sensors, more precise control, and shorter reaction time) which mean car trips will be safer [3]. The autonomous navigation of smart vehicles is a system that usually needs control to follow the path. This control system consists of longitudinal control devices and the lateral controller (side controls). The longitudinal control device is responsible for regulating the vehicle's cruising speed while the side controller directs the wheels of the vehicle to follow the path. Research on the

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autonomy of transportation systems has been continuously conducted both at home and abroad, and its representative field can be called autonomous driving technology [4].

Although there are some differences in the classification method for each researcher, the autonomous driving algorithm is largely composed of four stages: recognition, positioning, judgment, and control [5]. The recognition and positioning algorithm collects information about the surrounding environment using radar and location sensors attached to the vehicle and grasps the current location of the vehicle using GPS information. Using the information thus obtained, the vehicle's target path and speed are determined in the judgment stage. Finally, the step of applying an input so that the actual vehicle can follow the determined behavior corresponds to the control. The lateral behavior of the vehicle can be controlled through the steering wheel, and the lateral control algorithm is divided into upper control and lower control. The host controller determines the target steering angle based on the vehicle speed and position and the future path to be moved. In the case of an autonomous vehicle that must drive itself by an algorithm without the driver's steering wheel manipulation, the steering system is controlled by a separate operating device, which can be divided into sub-controls. When the technique of the control algorithm to be used is determined, there are variables that need to be tuned accordingly.

The gain increased by each mistake must be stated, as seen in [6], where Amiri Hossein investigated continuous path tracking analysis for automatic Electric Vehicles based on the PID control. To implement the nonlinear control technique studied by Elmokadem Taha et al. in [7], in which the terminal sliding mode control is used for trajectory tracking by under-actuated AUVs, the values of the feedback and feedback terms need to be calculated. The issue of steering control for car path tracking with unknown parameters and nonlinearities is explored in the aforementioned articles [8, 9]. For improved path tracking effectiveness of forward speed, road-tire adhesion coefficient, vehicle nominal cornering stiffness, and inertial parameters in the study in [10] offers an innovative adapt indirect control method based on an incredibly rapid fuzzy type-2 neural network method. The clever energy management system proposed by Reza Jazar et al. [11, 12] utilizes a fuzzy-logic-system to generate the desired engine torque in response to the road power requirement of the car and a PID processor to regulate the air-to-fuel ratio via adjustments to the throttle angle. When the GPS measurement is momentarily missing, some experts handle the path-tracking control problem of autonomous vehicles (AVs). Although the camera may not be able to determine the vehicle's status, its position, or the reference path's curve in such a scenario, it may be able to do so for the path tracking. Both articles [13,14] suggest a composite nonlinear feedback (CNF) controller based on a fuzzy observer and a Takagi-Sugeno (T-S) lateral dynamic model for the car, with the goals of ensuring a normal path-tracking move and enhancing transient performance.

There are parametric errors, external disruptions, and over-actuated characteristics in the class of driverless cars discussed in the article [15]. To monitor the sideways movement of autonomous four-wheel independent drive electric cars, a new adaptive hierarchical control structure is suggested. The pure pursuit steering control method introduced in the preview distance is used as a tuning variable [16], but the values of these detailed variables are often obtained through repeated experiments because there are many parts that are difficult to derive using only system modeling. Therefore, if the approximate range of applicable variables can be obtained theoretically, the time and effort required for detailed tuning can be reduced.

All the previous studies are concern either with the driving strategies while the detailed driving behaviors are low-level or specific traffic scenarios but lacked the high-level driving strategy studies. Research on the design of the controller that calculates the target steering angle and can stably follow it has been steadily progressing, but there is no optimal method that is considered to be the only correct answer yet. However, in this study, the determining of the tuning parameters of the transverse host controller using pure pursuit was proposed that we believe the comprehensive answer on how to proactively implement safe driving when using good characteristics of the vehicle and steering system. The main contribution of our work is to demonstrate suitability of steering system can give a satisfactory working during the sensors give a fusion information. We can obtain a good performance using a simple controller according to the formal fusion algorithm and the fault judgment rules method. it was verified using MATLAB/Simulink simulation

2. Transverse direction control system

The process from which the autonomous vehicle receives the target path and the actual steering control is performed and the vehicle behavior that occurs can be represented by the block diagram in

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Figure 1 [17]. The path tracking algorithm that calculates the Steering Wheel Angle (SWA) to estimate the target path corresponds to the upper control of the block diagram.

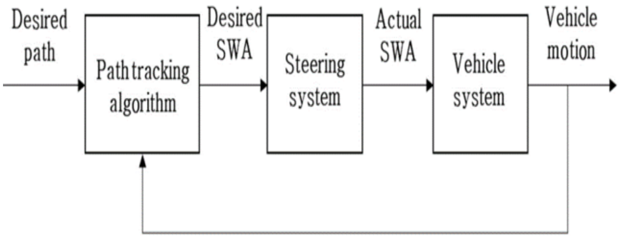

Figure 1: Schematic diagram of vehicle system control

3. Geometric Vehicle Model

The pure pursuit method was used for the upper control, and the principle is shown in Figure 1 It can be expressed as Unlike the error feedback control using the lateral error and azimuth error for the path, the pure pursuit method calculates the front wheel steering angle to be followed by defining a point on the target path from the current position of the vehicle every moment. Assuming that the tire slip angle is sufficiently small, when a certain steering angle is applied, the vehicle moves in an arc and its turning radius is as follows. [18].

$$\alpha = tan^{-1}(\frac{L_p}{2R}) \tag{1}$$

In Equation (1), R is the instantaneous turning radius of the vehicle, L_p is the preview distance for determining the target point on the path, and α is the angle corresponding to half the center angle of the circular path. The path that maintains the steering angle and allows the rear wheel center of the vehicle to be located at the target point is uniquely determined, and the most front wheel steering angle at this time.

In figure 2, L_w represents the wheelbase of the vehicle. In the case of α value, since the value changes according to the preview point and the position on the vehicle's path, the steering angle is actually determined by the two variables L_w and L_p. In the case of L_w, it is a value that is determined as one by the vehicle's own characteristics, so it can be considered that L_p is the only variable that needs tuning in the design of a host controller.

$$\alpha = 2\delta \tag{2}$$

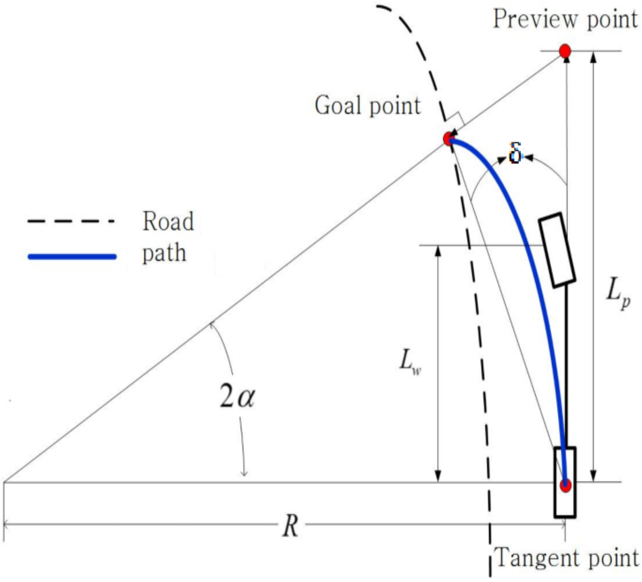

Figure 2: Geometric Bicycle Model and path tracking

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3. Steering Controller and System Identification

When the calculated target steering angle is applied to the steering system, the actual steering angle response of the vehicle is obtained through sub-control. The sub-controller controls actuators such as motors attached to the steering system to follow the target steering angle. Typically, a motor attached to a rack or column of an Electric Power Steering (EPS) system is used. The dynamic relationship of the steering angle to the input motor torque can be described as follows.

$$\theta_{sw}(J_{eq}S^2 + B_{eq}S + K_{eq}) = T_{mot} - T_{freq}\sin(\theta_{sw}) \tag{3}$$

In equation (3), J_{eq}, B_{eq}, and K_{eq} represent the equivalent inertia, equivalent damping, and equivalent stiffness of the steering system, respectively, and θsw represents the actual steering angle. T_{mot} and T_{fric} represent the torque applied by the motor and the torque loss due to the friction of the steering system [19]. Since the friction force is opposite to the direction of motion and the magnitude is constant, it is expressed as the product of the angular velocity sign and the friction force magnitude. If you follow the target steering angle while knowing the detailed characteristics of the steering system, you can calculate the required input torque through Equation (3) and consequently know the actual SWA response to the desired SWA. However, obtaining accurate system specifications and friction information for all vehicles is difficult, and if possible, it is quite inefficient because it requires a lot of time and effort. Therefore, in this study, the system identification method was used to estimate the transfer function between the target steering angle and the actual steering angle through an actuator experiment instead of directly obtaining system parameters.

MATLAB System Identification Toolbox provides the ability to calculate the transfer function of a given system given input and output data on the time axis. In order to acquire the data to be analyzed, the simulator was conducted using an actual Motor of vehicle and its EPS steering system. As shown in Table 1, the experiment was conducted by applying the step steering input in the constant speed driving situation, and the result showing one of the acquired data on the time axis is shown in Figure 3. For each experimental data, the transfer function of the steering system obtained by obtaining the first-order transfer function with time shift delay and taking the average value of the coefficients is as follows.

STEERING ACTUATOR'S VALUES

Speed	**Degree of steering**		
	20 Km/h	***50 Km/h***	***80 Km/h***
SWA degree	50^{o}	37^{o}	20^{o}

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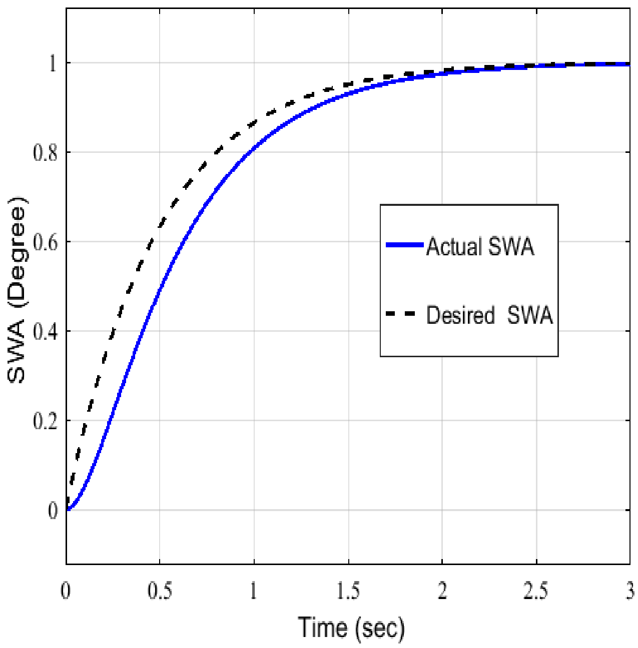

Figure 3: Time delay of steering SWA without ICs fusion

$$Transfere\ Function = \frac{1}{0.187S+1} e^{-0.23S} \tag{4}$$

□□□□□□□□□From the above equations, the preview distance L_p seems to be in a constant form, but it is appropriate to set it as a value that changes according to the speed. Grabbing the preview point has the meaning of receiving route information that exists in front of the current location. Considering the driving habit of the actual driver, if the speed increases, the vehicle drives away from the target point. That's, if the preview distance is set to be proportional to the driving speed, this value can be defined as follows.

$$L_p = k.v_x \tag{5}$$

v_x is the vehicle's longitudinal speed, and preview gain k has a time dimension. If k is small, the reaction speed of lateral motion may be faster, but there is a risk of vibration and divergence due to disturbance. Conversely, if k increases, there is an advantage in securing stability, but the convergence speed is slow, which acts as a disadvantage in terms of controller performance. Therefore, it is necessary to select an appropriate preview gain, but finding this value through direct experimentation for all vehicles cannot be an effective method, and it is difficult to find the theoretical meaning. However, by using the time delay effect and steering system characteristics that affect the lateral behavior, a condition of k that satisfies the stability can be found. [20]. If the input/output transfer function of the steering system obtained in Equation (4) is transformed into the Equation (6), it can be expressed as a system with the time constant T of 0.173 sec and the time delay (0.32 sec).

$$T.F. = \frac{1}{TS+1} e^{-\tau S} \tag{6}$$

In addition, in an autonomous driving situation, the total time delay τ_{tot} can be set to about 0.30 sec because it requires an operation time of about 150 msec for the entire module including recognition, positioning, and judgment to operate during one loop [8]. If the preview distance and the delay time are dimensionless made using the vehicle travel speed and time constant, two dimensionless variables L and τ can be obtained as shown in Equation (7) [18]. The relationship is shown in Figure 4.

$$L = K / (0.187) \quad \text{at} \quad \tau_{tot} = 1.0 \text{ sec} \tag{7}$$

$$K = 0.43\ S \tag{8}$$

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If we apply linear extrapolation without ICs Fusions to the relationship between L and τ shown in Figure 4 when τ = 1.0 sec we can obtain the value of k, it is as shown in Equation (8). Where v_x expressed in units of (m/s), the pure pursuit control method obtains a condition that a preview gain of at least 0.43 s is required to stably follow the target path.

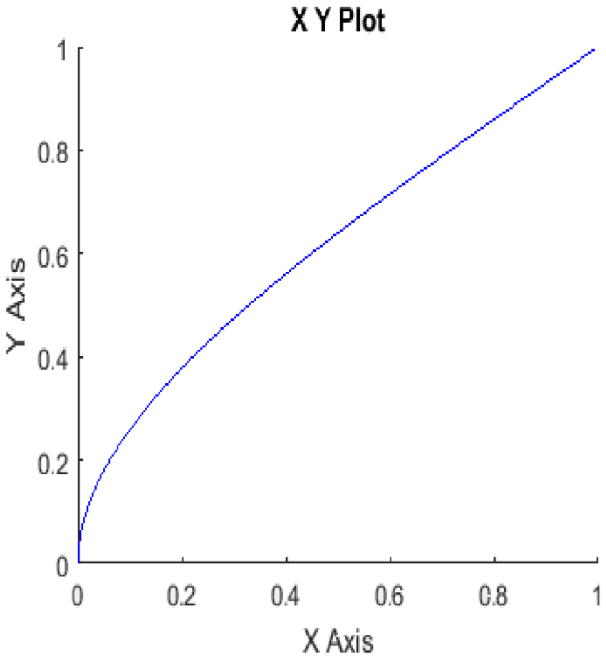

Figure 4: relation between L and τ without ICs fusion

4. Simulation results and discussion

A Path tracking simulation was performed to compare the vehicle behavior when the preview gain that satisfies the stability condition was applied with the case where other values were used. The path tracking and steering control algorithm was implemented in MATLAB Simulink and CarSim was used as the vehicle model as shown in figure 5. In order to implement the time delay effect and the steering system response effect, 0.13S zero-order hold and the transfer function block of Equation (4) were added to the previous stage of the steering wheel angle signal input to CarSim. The target path is shown in Figure 6. From figure 6 we find the system was manufactured by connecting a straight line and a 60° left turn section with a turning radius of 50 m. The driving scenario was set to maintain a constant longitudinal speed of 60 km/h without initial lateral error. Figure 7 shows the steering angle, lateral error (according the K-value which represent the resistance of ICs after fusion), and figure 8 shows the steering angle azimuth error with respect to time when the simulation is performed with the preview gain set to 0.2, 0.5, and 0.8 respectively. When the preview gain is 0.3, a lateral error occurs and the path tracking is not normally performed. As the k value increases, the steering angle and the vibration of the error tend to decrease. Comparing the k value of 0.4, 0.6 and 0.7, in the former case and, effectively raised the fault mode recognition and its ability, the magnitude of the steady state error in the rotating section is smaller than 0.3, but vibration remains high level. Therefore, since the lateral error is small, the path tracking performance can be considered optimal at 0.2, but it can be judged as a value that is insufficient in terms of: settling time, controller stability and robustness.

5. Discussion on Fault Diagnosis Results

A Path tracking simulation of steering control is greatly reduced during unidentified degree of the fault. When the fault of ICs apparatuses cannot be creating by use of three kinds of sensors distinctly, after fusion, we can exactly distinguish the fault component, due to its real situation. Then, multi-sensor information fusion based on the D-S evident theory enhanced the analyzability of the equipment, and elevated the fault components' orientation precision rate.

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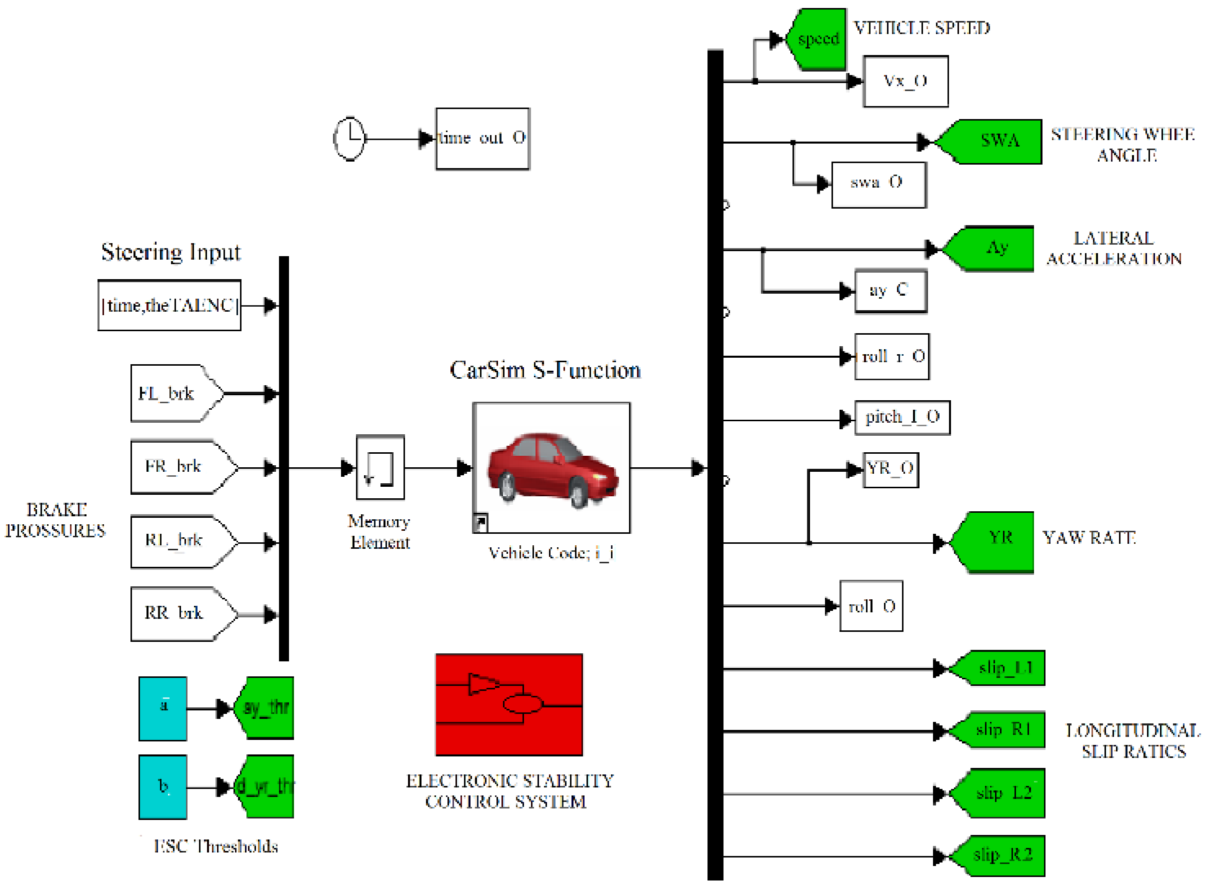

Figure 5: steering control implementation in MATLAB Simulink and CarSim

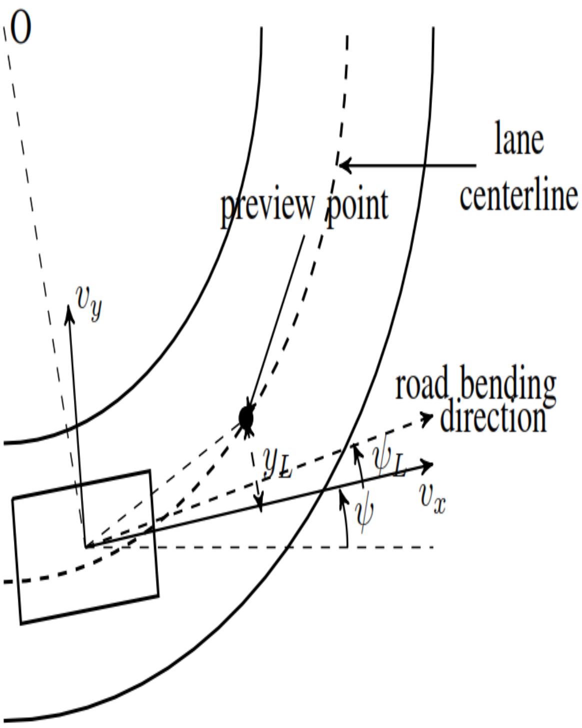

Figure 6: Reference path with road bending direction

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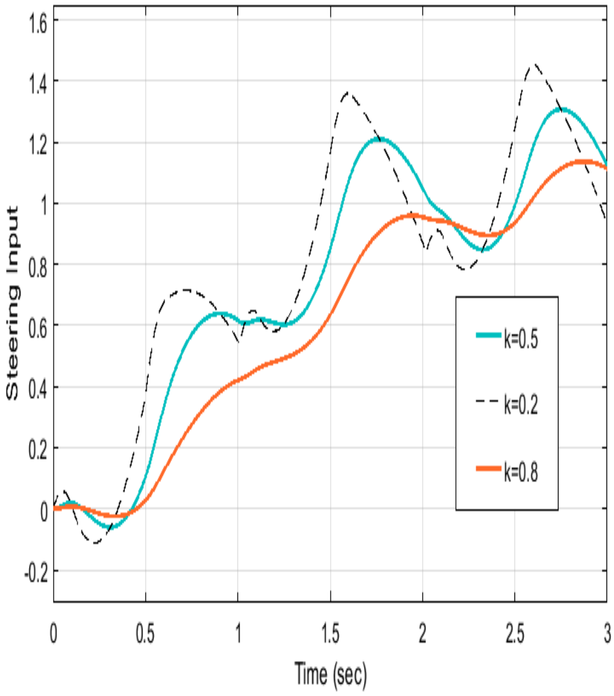

Figure 7: Path tracking simulation result of steering angle input

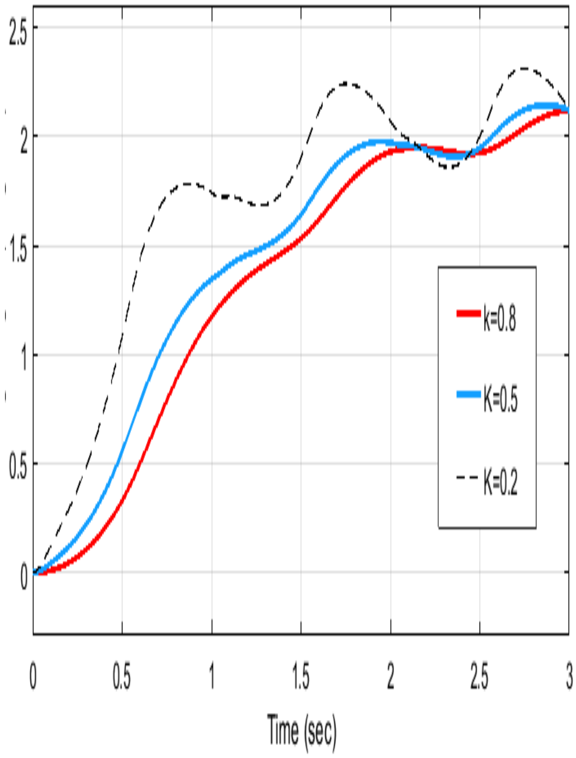

Figure 8: lateral and heading error for three different preview gain values

6. Conclusion

In this study, we introduced a system identification that can obtain the characteristics of a vehicle's steering system relatively simply and effectively, and present a method of using the obtained system time delay and time constant to determine the preview gain value in the pure pursuit method. In addition, in order to determine whether the calculated preview gain value is valid (0.2 0.5 and 0.8) or not (0.3,0.4, 0.6 and 0.7), the simulation

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was performed by setting different preview gains. When this value is less than a certain value as shown in figures 7, 8, The results are more favorable when compared to similar studies. it was confirmed that errors and vibrations at a level that makes it impossible to follow the path occur. The preview gain value in [8] does not provide an exact true value for the controller using the pure pursuit method to stabilize. However, since the path tracking simulation results show different patterns around this valid value, it is significant in that it is possible to know the range of preview gain values available to the controller by analyzing the characteristics of the vehicle and the steering system. In future work, we should study the root-locus and model-based method unaffected by road curvature is needed to lower the monitoring inaccuracy. Further trials are needed to validate the technology in a range of settings. Finally, the results of the three simulations above illustrate that the D-S information fusion circuit fault diagnosis method is more accurate than single sensor processing, and this is because the multi-sensor information fusion involves the integration of multiple.

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