Research Article

Longitudinal Control for Cruise Control Features in Vehicle Automation

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Abstract

This research focuses on longitudinal control methods implemented in Cruise Control (CC) and Adaptive Cruise Control (ACC) systems, as well as the mechanism for switching between these two modes. Two primary longitudinal control methods are examined: Constant Space Headway Control, which maintains a constant distance between vehicles, and Constant Time Headway Control, which maintains a constant time gap between vehicles.

The noteworthy feature of this research focuses on incorporating a switching mechanism between Cruise Control and Adaptive Cruise Control through the utilization of the virtual target method.

Keywords: Cruise Control, Adaptive Cruise Control, Constant Space Headway Control, Constant Time Headway Control, Hybrid Adaptive Cruise Control

1. Introduction

Over the decades, Automated Vehicle Control Systems (AVCS) have become an integral part of the Intelligent Vehicle Highway System (IVHS). The primary objective of IVHS is to introduce enhanced automatic features into vehicles through the integration of sensors, microcontrollers, and control systems. These features can range from simple Cruise Control to fully autonomous vehicles, where the vehicle systems operate without human drivers [1].

According to the SAE J3016 standard [2], vehicle automation is categorized into six levels, ranging from Level-0 (no autonomy) to Level-6 (full autonomy). Several car manufacturers are actively targeting different levels of automation. For instance, Tesla's Autopilot [3] operates at Level-1 or Level-2, primarily focusing on Advanced Driver Assistance Systems (ADAS). On the other hand, Waymo's autonomous vehicles [4] operate at Level-4 or Level-5, representing higher degrees of automation.

Longitudinal control in vehicles involves the detection of other vehicles in the same lane using sensors and the regulation of the distance or time gap between them [5]. The architecture of the longitudinal control system can be seen in Fig.1. Various longitudinal control features, such as Cruise Control, Adaptive Cruise Control, Emergency Brake Systems, and Collision Avoidance Systems, are designed to identify target vehicles and control throttle and brake actuators to achieve the necessary acceleration and deceleration [6].

Cruise Control, Adaptive Cruise Control, and Stop-and-Go Maneuvers serve as pivotal components of vehicle automation, representing initial steps toward assisting drivers on highways and in urban traffic. These systems take on the responsibility of managing the vehicle's speed by calculating the required acceleration and deceleration, allowing the driver to focus solely on vehicle orientation. The system autonomously adjusts the vehicle's speed and maintains a safe distance from the leading vehicle [7].

This research endeavors to delve into the multifaceted realm of longitudinal control within the domain of Vehicle Automation. The primary aim is to investigate the diverse types of longitudinal control systems employed in modern vehicles, with a keen focus on understanding the fundamental concept of Cruise Control (CC) and its pivotal role within this framework. Throughout this article, the different types of CC are explored and the technical components that make longitudinal control a driving force in enhancing both safety and driver convenience are examined.

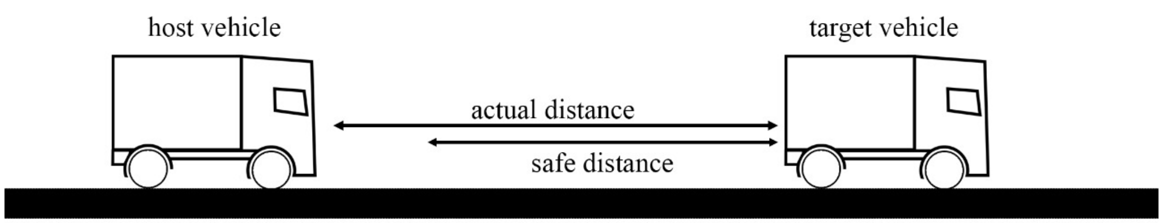

Fig. 1. Longitudinal Control System

2. Longitudinal Control Features

Longitudinal Control Systems rely on forward-looking sensors to detect the presence of a target vehicle. These systems employ a diverse array of sensors, including radar, LIDAR, ultrasound, localization technology, computer vision, and more, to precisely navigate along the intended path in the correct direction [6]. Longitudinal Control stands as a pivotal component within the realm of Advanced Driver Assistance Systems (ADAS) [8].

Among the noteworthy features of longitudinal control, the following can be ranked in the order of significance: Cruise Control (CC), Adaptive Cruise Control (ACC), Stop & Go Maneuvers, Autonomous Emergency Brake (AEB), and Forward Collision Warning System (FCW).

2.1. Cruise Control

Cruise Control (CC) takes control of the car's speed by maintaining a constant speed set by the driver. This system proves invaluable in alleviating driver fatigue during extended road trips.
The operation of the cruise control system involves two primary steps:

Setting the Desired Speed: The driver initiates the cruise control mode at their preferred speed. This can be done by simply engaging the cruise control mode at the desired speed, ensuring the car maintains that speed when activated. Alternatively, the driver can adjust the speed by tapping the "set/acceleration" button to increase speed or the "coast" button to decrease it.

Processing the Input: Within the system, a processing unit receives the driver's input signals and calculates the necessary acceleration and deceleration [9].

2.2. Adaptive Cruise Control

Adaptive Cruise Control (ACC) represents an advancement of the conventional cruise control system. ACC employs sensors such as radar or LIDAR to continuously monitor the relative speed and distance between the host vehicle and the target vehicle in front. Fig.2 represents the Adaptive Cruise Control System.

The operational principle of ACC is as follows:

Distance Maintenance: ACC automatically adjusts the vehicle's speed to maintain the preset following distance set by the driver. If the target vehicle ahead is traveling at a slower speed, the system will decrease the speed of the host vehicle while keeping a safe distance.

Speed Control: In the absence of a target vehicle in front or if the target vehicle accelerates beyond the preset following distance, the ACC system will restore the vehicle to the preset cruise control speed.

ACC enhances safety and convenience by dynamically adapting the vehicle's speed based on traffic conditions, reducing the need for manual speed adjustments by the driver [6,9].

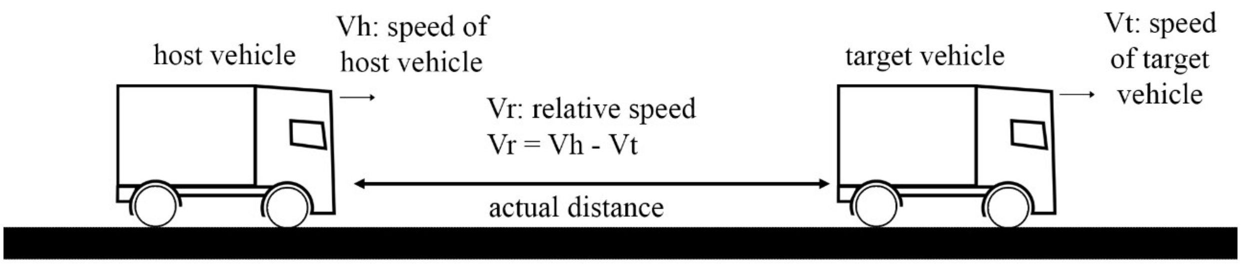

Fig. 1. Adaptive Cruise Control System

2.3. Stop & Go Maneuvers

While Adaptive Cruise Control (ACC) is primarily designed for highway use, functioning when the car's speed exceeds 40-30 km/h, Stop & Go Maneuvers are tailored for urban traffic situations when the vehicle's speed falls below this range. Unlike ACC, which hands control back to the driver below this speed threshold, Stop & Go Maneuvers continue to operate in lower-speed scenarios.

Key characteristics of Stop & Go Maneuvers include:

Aggressive Acceleration and Deceleration: This system is engineered with more assertive acceleration and deceleration limits compared to ACC. It's optimized for navigating congested traffic situations with frequent stops and starts.

Traffic Jam Capabilities: Stop & Go Maneuvers can effectively bring the vehicle to a complete stop and resume motion in traffic jams, providing enhanced convenience and reducing the driver's workload [6,9].

In summary, Stop & Go Maneuvers are tailored to handle lower-speed, stop-and-go traffic scenarios commonly encountered in urban areas, making them a valuable addition to advanced driver assistance systems.

3. Longitudinal Control Approaches

In Longitudinal Control plays a crucial role in aiding drivers in the management of their vehicle's speed by aiding with brake and accelerator operations. It operates based on three primary inputs: the current speed of the vehicle, the desired speed set by the driver, and distance measurements obtained from sensors. The longitudinal control features, including Cruise Control (CC), Adaptive Cruise Control (ACC), Stop & Go, among others, are responsible for computing the necessary acceleration or deceleration of the vehicle based on these inputs and control algorithms [10].

To assess the effectiveness of ACC systems, three distinct control approaches are considered: Constant Space Headway Control (CSH), Constant Time Headway Control (CTH), and Variable Time Headway Control (VTH)[11].

These approaches play a vital role in fine-tuning the behavior of ACC systems to meet various driving conditions and preferences.

3.1. Constant Space Headway Control

Constant Space Headway Control is an approach that maintains a consistent distance between vehicles while in operation. This distance is calculated based on several factors, including the desired speed set by the driver and specific limitations defined by regulations and standards [12].

The operational principle of Constant Space Headway Control is as follows:

Distance Calculation: The system calculates the appropriate following distance based on the driver's chosen speed and regulatory constraints. This ensures that the vehicle maintains a safe separation from the one in front.

Regulatory Compliance: Constant Space Headway Control adheres to established regulations and industry standards to determine the minimum safe following distance, considering factors such as speed limits and safety guidelines.

By maintaining a constant space between vehicles, this control approach enhances safety and contributes to smoother traffic flow.

3.2. Constant Time Headway Control

Constant Time Headway Control is an approach that maintains a consistent time gap between vehicles, determined by the desired speed set by the driver. The control system calculates the desired following distance by multiplying the chosen time gap by the vehicle's speed. This approach ensures string stability in the system while also guaranteeing smooth acceleration and deceleration [1].

The operational principle of Constant Time Headway Control is as follows:

Time Gap Calculation: The system calculates the appropriate time gap based on the driver's selected speed. This calculated time gap is then used to establish the desired following distance, considering the vehicle's current speed.

String Stability: Constant Time Headway Control is designed to ensure the stability of the vehicle string (a line of vehicles traveling in the same direction) by maintaining consistent time gaps between them.

Acceleration and Deceleration: By adjusting the vehicle's speed to maintain the desired time gap, this control approach achieves smooth acceleration and deceleration, contributing to a more comfortable and safe driving experience.

Constant Time Headway Control is particularly effective in situations where maintaining a consistent time gap between vehicles is crucial, such as in dense traffic conditions.

3.3. Variable Time Headway Control

Variable Time Headway Control is an approach that dynamically regulates the desired following distance between vehicles based on their relative velocities. Unlike Constant Time Headway Control, where the time gap remains constant, Variable Time Headway Control continuously adjusts the time gap value as circumstances change [13].

The operational principle of Variable Time Headway Control is as follows:

Dynamic Distance Regulation: The system continually adapts the desired following distance between the host vehicle and the target vehicle in front based on their relative velocities. As the relative velocity changes, the time gap value is adjusted accordingly.

Real-Time Responsiveness: Variable Time Headway Control offers real-time responsiveness to the traffic situation. It allows for greater flexibility in maintaining safety distances, especially in situations where traffic conditions fluctuate rapidly.

Optimizing Traffic Flow: By dynamically regulating the following distance, this control approach can contribute to smoother traffic flow and more efficient use of road space. Variable Time Headway Control is particularly valuable in congested traffic scenarios where vehicles frequently change speeds, providing enhanced safety and traffic management.

4. Switching between Cruise Control and Adaptive Cruise Control

Cruise Control (CC) and Adaptive Cruise Control (ACC) can be integrated within a vehicle's control system. While CC maintains a constant driver-set speed and ACC adjusts speed based on sensor data to maintain a safe following distance, the key to seamless switching between these modes lies in the virtual target model. This model dynamically determines the appropriate mode based on real-time data. When the system determines the need, it transitions seamlessly between CC and ACC, enhancing safety and driver convenience.

4.1. Virtual Target Model

The Virtual Target Model plays a pivotal role in seamlessly transitioning between Cruise Control (CC) and Adaptive Cruise Control (ACC). Even when there is no target vehicle directly ahead of the host vehicle, the system defines a virtual target. This virtual target shares the same speed as the host vehicle, while the distance is determined based on the selected longitudinal control approach [14]. Fig.3 represents architecture of virtual target model.

Modes of operation for the Virtual Target Model is described as follows:

CC Mode: When there is no real target vehicle in front, or when the relative distance between the real target vehicle and the host vehicle is greater than that between the virtual target and the host vehicle, the system operates in CC mode. In CC mode, the vehicle maintains a constant speed set by the driver.

ACC Mode: When the relative distance between the real target vehicle and the host vehicle is smaller than that between the virtual target and the host vehicle, the system transitions to ACC mode. In ACC mode, the vehicle adjusts its speed based on sensor data to maintain a safe following distance from the real target vehicle.

Dynamic Mode Transition: Depending on the current traffic situation and real-time data, the system may transition between CC and ACC modes as needed to ensure safety and optimize driving conditions.

The Virtual Target Model enhances overall safety and driver convenience by determining the most suitable mode based on the presence and relative distance of real target vehicles.

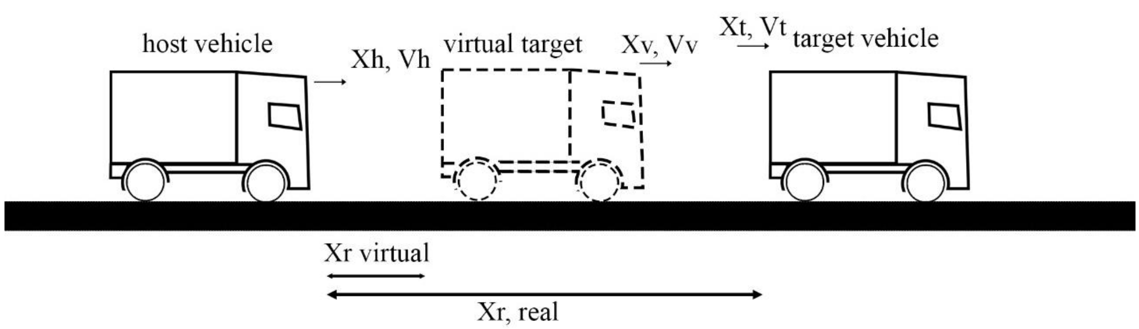

Fig. 3. Architecture of virtual target model

5. Limitations

The Longitudinal control systems in the market come with certain limitations, some of which are dictated by industry standards, while others are defined by companies to ensure system requirements, customer safety, and comfort.

Speed Range: Adaptive Cruise Control (ACC) typically operates between speeds of 40 km/h and 250 km/h, making it suitable for highway driving. Stop and Go maneuvers are designed for speeds below 40 km/h [15].

Acceleration Limits: ACC systems are subject to acceleration limitations, typically around ±3 m/s^2. These limits are in place to prioritize driver safety and comfort.

Inter-Vehicle Distance: The inter-vehicle distance is subject to variation based on the local regulations of a given location but usually yields similar results.

In Turkey, regulations regarding inter-vehicle distance recommend maintaining a distance equivalent to at least half of their own vehicle's speed in kilometers per hour, measured in meters. This can also be approximated as the distance a vehicle can cover in 2 seconds, measured in meters, for every 1 kmph of speed. For instance, when traveling at 40 kmph, the recommended safety distance is approximately 20 meters, while at 60 kmph, it extends to around 30 meters [16].

In contrast, California's regulations stipulate a different approach to inter-vehicle distance. It is recommended to maintain a distance equivalent to one vehicle length (approximately 4.5 meters on average) for every 10 mph of speed. Therefore, when traveling at 40 kmph, the recommended distance is about 18 meters, and at 60 kmph, the recommended distance is approximately 27 meters [17].

This policy considers the reaction time of human drivers in a conservative manner, contributing to overall safety.

6. Conclusions

In the ever-evolving landscape of automated vehicle control, longitudinal control systems have emerged as indispensable tools, reshaping the way we drive. From the simplicity of Cruise Control (CC) to the sophistication of Adaptive Cruise Control (ACC) and Stop & Go maneuvers, these technologies have not only improved driving comfort but also significantly enhanced road safety.

CC, with its ability to maintain a constant speed set by the driver, has reduced driver fatigue on long journeys. ACC takes this concept a step further, seamlessly integrating sensor data to dynamically adjust speeds, ensuring a safe following distance from other vehicles. In bustling urban environments, Stop & Go maneuvers come into play, providing agile acceleration and deceleration for speeds under 40 km/h.

While recognizing the constraints of longitudinal control systems, such as speed limitations, acceleration bounds, and recommended inter-vehicle distances, is critical to maintain safety and driver comfort, it's important to note that the Virtual Target Model serves as an essential model within this framework. This intelligent model responds to real-time data, effortlessly transitioning between modes to optimize speed control for diverse driving scenarios.

In summary, longitudinal control systems have changed the way we drive, enhancing safety and comfort. They are vital in the ongoing evolution of driving, promising a future of safer roads and more convenient journeys.

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