SAFE AND ENERGY-EFFICIENT JERK-CONTROLLED SPEED PROFILING FOR ON-ROAD AUTONOMOUS VEHICLES

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Abstract: Efficient speed planning is crucial for the safe and comfortable navigation of autonomous vehicles in dynamic environments. This Project introduces a novel energy-efficient, jerk-controlled speed planning approach based on quintic polynomial generation. We present a systematic methodology to determine the dynamic speed of autonomous vehicles by integrating several factors, including the relative velocity with dynamic obstacles, the curvature of the base frame and optimal selected path, road adherence, and road gradient. The direct integration of road adherence and gradient into the speed profiling approach contributes to improving vehicle safety. Comparative analysis with literature methods demonstrates the significant impact of jerk smoothness on energy efficiency. Simulations are conducted in a joint simulation between Simulink and SCANeR Studio vehicle dynamics simulator, followed by validation on a real-world dataset. Our findings elucidate the significance of the proposed planning method in enhancing safety, energy economy, driving comfort, and computational efficiency, while effectively addressing a wide range of critical situations.

1. INTRODUCTION

Ride comfort has recently received much attention in different driving scenarios due to its influence on the public acceptance of autonomous vehicles (AVs) and the health of passengers Ride comfort is a subjective sensation of passengers associated with the motion of vehicles in different directions. In longitudinal motion, car following is the most frequent scenario. The main task of autonomous car following is maintaining safe and comfortable following gaps via speed control. Regarding vertical motion, the comfort issues caused by dramatic vehicle body vibration on rough pavements are concerned. Speed control helps mitigate vertical vibration on rough pavements. However, safe, efficient, and comfortable speed control is rarely achieved in driving scenarios with car following and rough pavements. Indeed, simultaneously considering pavement conditions and vehicles in front is challenging for a human driver. Heavy congestion and traffic crashes are common on poor roads in peak periods. In this complex driving scenario, intelligent speed control of AVs promises to improve safety, efficiency, and ride comfort and mitigate driver workload. For car-following behavior, rule-based and supervised learning-based approaches are used to establish car-following models. In rule-based approaches, conventional car-following models are usually used. However, the rule-based approaches involve strong assumptions and simplification, limiting their real-world application. Supervised learning approaches investigate the relationship between dynamic traffic and acceleration selection using extensive expert demonstrations. However, supervised learning only imitates human driving. Although neural networks can generate outputs regardless of inputs, the generalization capability is limited. Thus, for some untrained complex situations, it is difficult for supervised learning-based approaches to find optimal solutions. For speed control on rough pavements, model-based speed planning, such as dynamic programming, is commonly used. However, model-based speed planning is also based on strong assumptions of the environment, so it struggles to address changing environments. The application of model-free DRL algorithms in dynamic traffic scenarios has recently been researched. For example, Zhu et al. trained a DRL-based car-following model using 2000 periods of car following on urban expressways in Shanghai to outperform conventional car- following models. Wu et al. trained a DRL-based differential variable speed limit controller to improve safety, efficiency, and environmental friendliness on freeways. The experimental results show that the controller reduces travel times and CO2 emissions. Mao et al. proposed a DRL-based framework to address the taxi dispatch problem with the imbalance of travel demand and taxi supply. The framework outperforms the vanilla policy gradient method and shallow neural networks regarding convergence rate and quality. The above studies suggest that good performance and broad application of model-free DRL algorithms can be achieved in intelligent control. In DRL-based speed control, a deep deterministic policy gradient (DDPG) algorithm has been widely used. Zhu et al. proposed a DDPG-based speed control for safe, efficient, and comfortable car-following behavior, which outperforms human drivers and model predictive control (MPC) . However, this DDPG model only considered the dynamics of leading and following vehicles. In practice, driving environments are complex. For example, road alignment impacts vehicle dynamics and driving stability, and pavement conditions influence vehicle body vibration. Buechel and Knoll developed a DDPG-based predictive longitudinal controller that directly selects accelerations according to reference speeds and road grades. Subsequently, the authors of this study have used the DDPG algorithm to control the speed with prior knowledge of the dynamic speed limit and comfortable speeds on rough pavements. However, it only provides a solution to a multi-objective speed control problem for an AV without consideration of surrounding vehicles. Since the DDPG-based speed control has the characteristics of fast computation, superior driving performance, and good scalability, it promises to be a popular speed control approach in the era of autonomous driving. Thus, it is necessary to modify the existing DDPG-based speed control and extend application scenarios. In this study, we proposed an intelligent speed control approach for safe, efficient, and comfortable car-following on rough pavements using the DDPG algorithm. As shown in Figure 1, the proposed speed control approach is applied in a cooperative vehicle infrastructure system (CVIS). In this system, AVs detect road profiles using onboard light detection and ranging (LiDAR), accelerometers, and C (GPSs) and then send them to roadside units (RSUs) via vehicle-to-infrastructure communication. Dynamic traffic information can be detected by roadside sensors. Furthermore, the multi-source road and traffic information is uploaded to the cloud server for integration. When an AV enters the road, it receives complete road profiles of the pavement. The AV then extracts the road profiles of the left and right wheels along the trajectory and calculates comfortable speeds on segments by vertical comfort evaluation. Meanwhile, the AV receives the location and speed information of surrounding vehicles, especially the leading vehicle, via vehicle-to-vehicle communication. Finally, the DRL-based speed control observes the information on comfortable speeds and leading vehicle and recommends accelerations. The AV adjusts driving speed to achieve safe, efficient, and comfortable driving according to recommended accelerations.

The contributions of this study are as follows:

(i) The application of DDPG-based speed control is extended to a scenario with car following and rough pavements, contributing to driving performance improvement and drivers' workload mitigation in complex driving scenarios.

(ii) A novel reward function is designed by incorporating safety, efficiency, vertical comfort, and longitudinal comfort regarding time to collision, time headway, clearance distance, annoyance rate, jerk, and acceleration.

(iii) The proposed intelligent speed control provides an approach for longitudinal acceleration selection based on dynamic traffic and road information in a CVIS.

2. EXISTING SYSTEM

Traditional speed profiling methods for autonomous vehicles often prioritize reaching target speeds and following routes without considering the smoothness of acceleration and deceleration. This can lead to sudden jerks, which reduce passenger comfort, increase energy consumption, and cause wear on vehicle components.

3 Proposed System

The proposed system presents a safe and energy-efficient jerk-controlled speed profiling mechanism for autonomous vehicle applications using an embedded platform. The system is designed to ensure smooth vehicle motion by minimizing sudden acceleration and deceleration, thereby reducing jerk and improving passenger comfort.

The architecture consists of a microcontroller-based control unit integrated with multiple sensors and actuators. The system continuously monitors environmental conditions such as obstacle distance, object detection, and identification through sensors. Based on the acquired data, the controller dynamically adjusts the speed of the vehicle to maintain safety and efficiency.

The block diagram illustrates that the central control unit (Raspberry Pi Pico) receives inputs from sensors such as the ultrasonic sensor, IR sensor, and RFID module. These sensors provide real-time information about obstacles, proximity, and identification of specific zones or objects.

The processed data is used to:

- Control the speed of the DC motor
- Trigger alerts using a buzzer
- Display system status on the OLED screen

A regulated power supply ensures stable operation of all components. The system follows a closed-loop control mechanism where continuous feedback from sensors helps in achieving smooth speed transitions and jerk minimization.

4. BLOCK DIAGRAM:

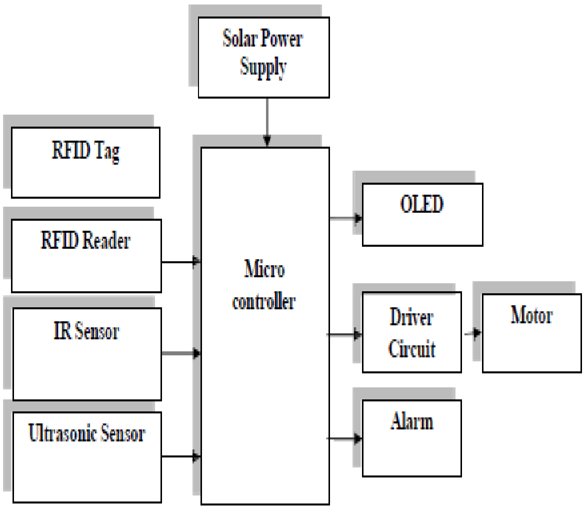

Fig.1:block diagram

5. Modules:

A. Microcontroller Unit (Raspberry Pi Pico)

The Raspberry Pi Pico acts as the central processing unit of the system. It is based on the RP2040 microcontroller and is responsible for:

- Processing sensor inputs
- Executing control algorithms
- Generating output signals to actuators

Its high processing speed and multiple GPIO pins make it suitable for real-time embedded applications.

B. Ultrasonic Sensor

The ultrasonic sensor is used for distance measurement and obstacle detection. It operates by transmitting ultrasonic waves and measuring the time taken for the echo to return.

Function:

- Detect obstacles ahead
- Calculate distance
- Assist in speed adjustment

This helps in preventing collisions and ensures safe vehicle operation.

C. IR Sensor

The IR sensor is used for short-range object detection. It detects obstacles by sensing reflected infrared radiation.

Function:

- Detect nearby objects
- Provide quick response in close-range scenarios

It complements the ultrasonic sensor for improved accuracy.

D. RFID Module

The RFID system consists of a reader and tags. It is used for identification and access control**.**

Function:

- Identify predefined zones or signals
- Enable conditional control actions (e.g., speed limits, stopping zones)

This enhances automation and intelligent decision-making.

E. DC Motor

The DC motor represents the vehicle's propulsion system**.**

Function:

- Execute speed control commands
- Adjust motion based on sensor inputs

The speed of the motor is controlled to achieve smooth acceleration and deceleration.

F. Motor Driver (ULN2003)

The motor driver acts as an interface between the microcontroller and the motor.

Function:

- Amplify control signals
- Drive the motor safely

It protects the microcontroller from high current loads.

G. Relay

The relay is an electrically operated switch used to control high-power devices.

Function:

- Switch motor ON/OFF
- Provide isolation between control and power circuits

H. OLED Display

The OLED display is used for visual output**.**

Function:

- Display system status
- Show distance and alerts

It provides real-time feedback to the user.

I. Buzzer

The buzzer provides audio alerts.

Function:

- Warn about obstacles
- Indicate system status

J. Power Supply Unit

The power supply provides a regulated DC voltage to all components.

Function:

- Convert AC to DC
- Maintain stable voltage using regulators

This ensures reliable system performance.

6. Working

The proposed system works by continuously monitoring the surroundings of the vehicle and adjusting its speed in a smooth and energy-efficient manner using jerk-controlled speed profiling. Initially, a regulated power supply provides a stable voltage to all components. Sensors such as the ultrasonic sensor and IR sensor detect obstacles and measure the distance from nearby objects, while the RFID module identifies specific zones or conditions. These inputs are sent to the Raspberry Pi Pico microcontroller, which acts as the central processing unit. The controller analyzes real-time data and calculates the appropriate speed by considering safety, distance, and driving conditions. Instead of sudden acceleration or braking, the system uses jerk control to ensure gradual changes in speed, thereby improving passenger comfort and reducing energy consumption. Based on these calculations, the motor driver controls the DC motor to adjust the vehicle’s movement accordingly. Additionally, the OLED display shows system status and sensor information, while a buzzer provides alerts when obstacles are too close. Thus, the system ensures safe, smooth, and efficient autonomous vehicle operation.

7. Algorithm

1. Start the system.
2. Initialize all components such as power supply, microcontroller, sensors (Ultrasonic, IR, RFID), motor driver, OLED display, and buzzer.
3. Read input data from sensors:
    - Measure distance using the ultrasonic sensor
    - Detect obstacles using the IR sensor
    - Read tag information using RFID module
4. Send all sensor data to the microcontroller.
5. Process the received data to analyze:
    - Distance from obstacles
    - Road or zone information (from RFID)
6. Calculate the required speed based on safety conditions.
7. Apply jerk-controlled logic to ensure smooth acceleration or deceleration.
8. If an obstacle is detected within a threshold distance:
    - Reduce speed gradually
    - Stop the vehicle if necessary
    - Activate buzzer alert
9. Otherwise:
    - Maintain or increase speed smoothly
10. Control the DC motor through the motor driver based on calculated speed.
11. Display system status and sensor values on OLED display.
12. Repeat the process continuously for real-time operation.
13. Stop the system when power is turned OFF.

8. Schematic Diagram

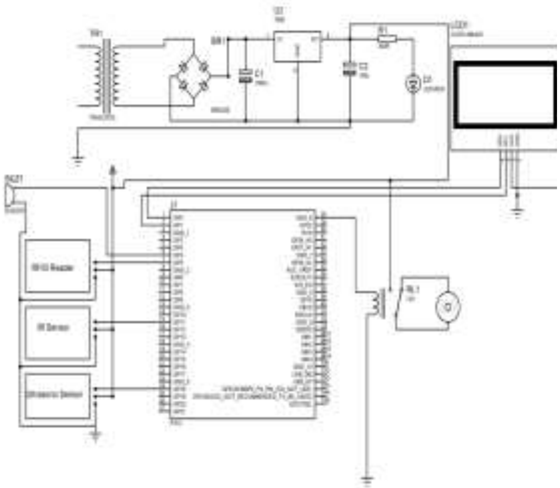

Fig 2: Ciruit Diagram

8.1 OUTPUT SCREENSHOT

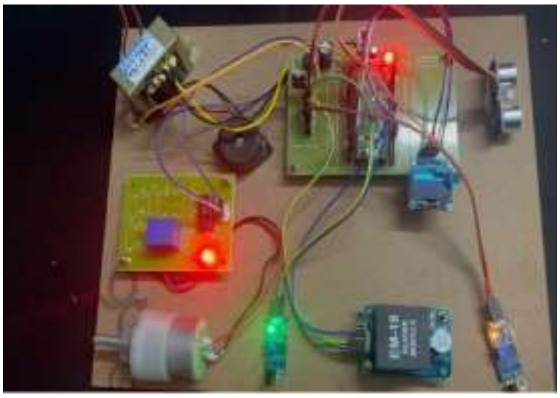

Fig.3: show final output results

Fig. 4:The OLED display shows the values.

The Design of the RFID-based jerk-controlled speed profiling system for autonomous vehicles consists of an integrated hardware and software architecture that ensures safe and smooth vehicle operation in restricted zones. The system includes RFID tags embedded along roadways at critical locations such as schools, hospitals, and speed breakers, while the vehicle is equipped with an RFID reader, microcontroller (such as Arduino or ECU), motor driver, and speed sensors. When the vehicle approaches a tagged zone, the RFID reader detects the tag and sends a signal to the controller, which identifies the type of zone and retrieves a predefined speed profile. Instead of applying abrupt braking, the controller implements a jerk-controlled speed trajectory, where acceleration is reduced gradually to minimize sudden changes, ensuring passenger comfort and vehicle stability. The design also includes feedback from speed sensors to continuously monitor and adjust the motor input, maintaining the desired velocity profile. For simulation, the system can be modeled using tools like MATLAB/Simulink, where the vehicle dynamics, motor model, and control algorithm are represented mathematically. The jerk-controlled profile is typically implemented using an S-curve (smooth polynomial) trajectory, which limits jerk by controlling the rate of change of acceleration. In simulation, different scenarios such as entering a school zone or encountering a speed breaker are tested by triggering virtual RFID signals. The results show that compared to conventional braking, the jerk-controlled approach produces smooth velocity, acceleration, and jerk curves, reducing mechanical stress and energy consumption. The simulation also helps in tuning parameters such as maximum speed, deceleration rate, and jerk limits to achieve optimal performance. Overall, the combined design and simulation validate that the system effectively enhances safety, ride comfort, and energy efficiency in autonomous vehicle operation.

9. Conclusion

To summarize, the study of proposes an intelligent speed control approach for autonomous car following on rough pavements in a cooperative vehicle infrastructure system using deep reinforcement learning (DRL). In experiments, the car-following events in the NGSIM data and road profiles in the rough pavement dataset are used for model training and testing. The experimental results show that the proposed DRL-based speed control has a better driving performance than a model predictive control baseline. Specifically, the DRL-based speed control can improve computational efficiency, driving efficiency, longitudinal comfort, and vertical comfort in car following by 93.47%, 26.99%, 58.33%, and 6.05%, respectively. The results indicate that the proposed intelligent speed control can contribute to autonomous driving on rough pavements and has excellent potential for practical application. In our future research, we plan to extend driving scenarios with lane-changing behavior. Although lane changing does not have the highest priority in conservative driving strategies, it remains a challenging task with the requirements of safe and comfortable trajectory planning . Meanwhile, the proposed intelligent speed control approach can be applied to several AVs with multi-agent RL and used to improve the driving performance in an environment of fully or partially AVs. Moreover, transfer learning and ensemble learning can be used to improve the training efficiency, robustness, and reliability of DRL models.

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