Fuel Efficient Racing Vehicle Driving Assistance System

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Abstract: EP (Eco-Power) racing is a competitive activity that challenges the limits of fuel consumption which helps promote technological innovation, environmental protection, and public awareness of energy saving and emission reduction. In this paper, an intelligent assisted driving system is developed for the actual energy-saving needs of EP racing cars. Among them, the hardware device designed by independent innovation can reduce the electronic circuit arrangement of the whole vehicle by more than 30% and improve the data transmission performance. The dynamic driving strategy planning uses a combination of dynamics model and LSTM neural network to predict the position of acceleration point on average 6.19s in advance. The final test results on a student EP race car showed that the driver assistance system was able to reduce fuel consumption by an average of 5.37%, achieving the expected results.

Key words: Fuel-efficient racing cars, Assisted driving, Filtering algorithm, LSTM neural network

Introduction

With the development of human society, energy crisis, environmental pollution, traffic congestion and other problems are becoming increasingly serious, and the requirements for low-carbon development, energy saving and emission reduction of the automobile industry are becoming more and more urgent. The Z series prototype is a competition modelwhich we developed for a series of energy-saving competitions, and the goal is to achieve the lowest fuel consumption within the scope permitted by the competition rules. In addition to the physical parts of power unit, underpan, and exterior design, the driver's driving strategy also has a significant impact on the car performance, among which acceleration and taxi timing are particularly critical.

In terms of vehicle speed measurement, Chi Yangbin et al[1] proposed that velocity measurements are achieved by placing two electrodes at a fixed distance to detect the characteristic times. Elnaz Vakili[2] et al proposed a new method based on the geometry of the imaging system and the definition of solid angle by a single camera which does not require 3D modeling. However, the realization of these methods has high requirements for the quality and layout of the equipment and the computing and processing ability of the control core, which is not suitable for the energy-saving prototype car with low weight, and simple structure. Wang et al[3] proposed the designing strategy of a motor speed measurement system based on a single-chip microcontroller with an integrated chip. In terms of driving strategy, Xiong Shuo[4] recognized the impact of driving strategies on energy consumption in the design of autonomous vehicles. He explored the influence of driving strategies on energy consumption by refining patterns through simulations in Carsim. Although the application scenarios differ significantly from ours, it provides insights into the design of driving strategies for my race vehicle. In terms of energy utilization, Chen Jing[5] conducted research on energy management strategies in hybrid power systems, aiming to achieve energy efficiency through torque distribution strategies for power sources.

In this paper, we propose an intelligent Energy-saving racing vehicle driving assistance system based on the actual energy-saving needs of EP racing cars. We optimize the printed circuit board (PCB), which is a reference for the hardware design and electrical wiring arrangement of the whole car. We write the STM32 micro CM algorithm based on the Hall sensor and design an exclusive APP with data display, filter processing, automatic timing, and other functions. We also provide a new idea to study the speed distribution of the fuel-efficient car race, i. e., to accurately predict the acceleration position of the fuel-efficient car.

1 Hardware

During the test drive, our electronic control part needs to complete the speed measurement and enrich other functions as much as possible. In order to achieve the above functions, we need to design the hardware of the electronic control part.

1.1 Onboard hardware system for daily use and debugging

In previous experiments, most of them used the connection of the demo board and DuPont line, which is convenient to debug and change the line. But in the experiment, inevitably, there will be some loose connections. And it takes a long time to find the part that needs to be changed when you change the line. To solve this problem, we designed a PCB that preserves interfaces for lines that may change during the experiment and integrates the parts that do not need to be changed. This greatly reduces the volume and weight of the electronic control part used at ordinary times.

This board realizes the functions of speed measurement and preserves interfaces for other functions that will be changed. For the prototype car's daily working conditions, we designed and manufactured the core board using chip STM32F103C8T6.

In practical application scenarios, vibration and the possible entry of dust into the electronic control box can occur. Therefore, when designing PCBs, isolation is applied to the power and signal circuits to reduce interference with data, increase system reliability, and the external casing is statically shielded to prevent other vehicle circuits[6] from affecting the electronic control part. In addition, in the power supply circuit section, there are devices with different voltages, and corresponding isolation measures are taken for different voltages to prevent potential issues.

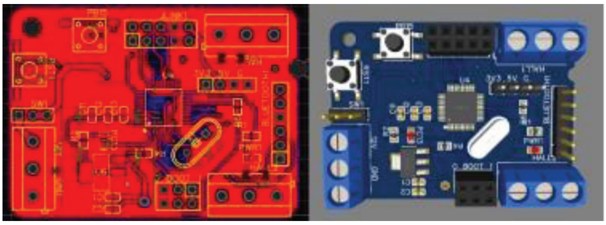

Fig. 1　PCB and 3D model of the electronic control part

1.2　Onboard hardware system of the driving strategic planning module

In the usual experiments, we will also make innovations in some functions. For the driving strategy mentioned earlier, we will simplify and improve the circuit of its hardware.

The driving strategy planning module is divided into an onboard hardware system and a host computer hardware system. Among them, the onboard hardware system needs to

1. realize the collection of wheel speed through the Hall wheel speed sensor,

2. realize the collection of vehicle position information through the GPS sensor,

3. send the encoded vehicle information data packet to the host computer through wireless communication equipment,

4. receive and unpack the driving strategy data package sent by the host computer.

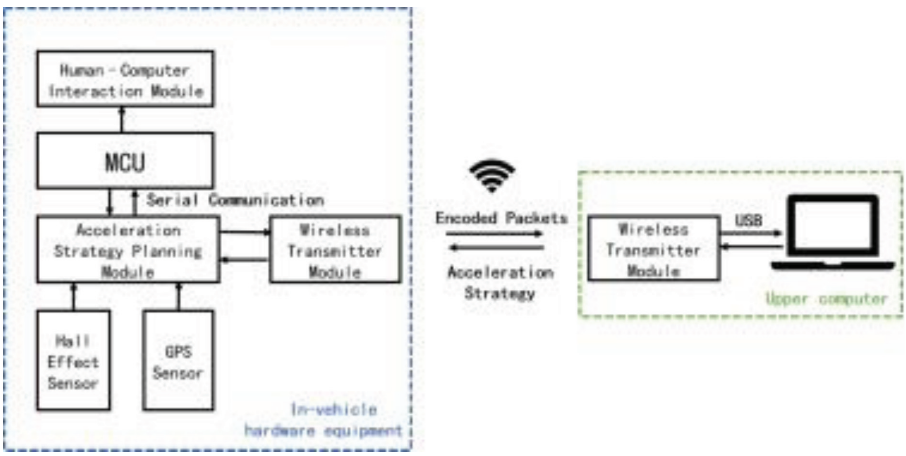

Fig. 2　System Block Diagram

Modular design is adopted in the hardware to facilitate manufacturing, debugging, and upgrading.

We used Altium Designer to design the core board, backplane, and wireless communication equipment.

1.2.1　Backplane design

The backplane integrates M6N GPS, HC-05-BlueTooth module, power management module, 433Mhz wireless transmitter module, and various sensors and displays device expansion ports. All functional parts in the backplane can be directly replaced, which significantly reduces the difficulty of debugging and upgrading.

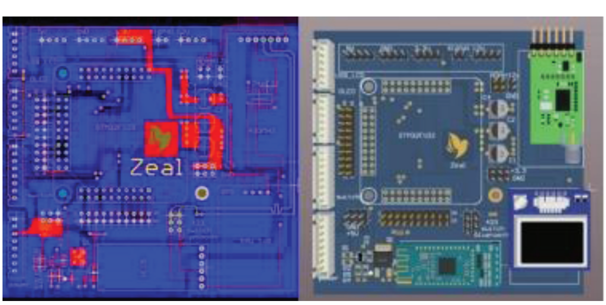

Fig. 3　PCB and 3D model of Backplane

1.2.2　Core board design

The core board realizes the functions of data encoding, calculation, and decoding. For the prototype car's particular working conditions, we designed and manufactured the core board using chip STM32-F103RCT6.

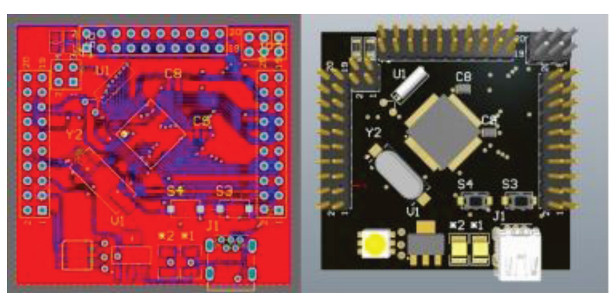

Fig. 4　PCB and 3D model of the core board

1.2.3　Wireless transmitter module design

The wireless transmitter module handles the transmission of vehicle information data and Calculated driving strategy data. We used the SX1278 chip[7], which can achieve stable data transmission under conditions of 8km and 19.2kBit/s during the test drive.

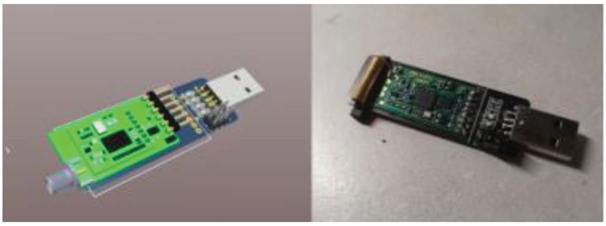

Fig. 5 Wireless transmitter module

1.2.4 Hardware assembly

We made a prototype machine[8], and its performance fully met the design specifications.

Fig. 6 Hardware assembly

In short, the driving strategy planning algorithm is to predict when and where the vehicle will reach critical conditions through a specific program, thereby automatically planning the optimal driving strategy. The primary function is to input vehicle status information and feedback driving strategy.

2 Software

2.1 Speed Measurement

In the process of energy-saving car competition, there are many factors that affect the competition results. Among them, grasping the appropriate acceleration and sliding timing has a great impact on the competition results. If you want to do a good job, you must first sharpen your tools. Therefore, further improving the development of software and hardware and having a precise and fast vehicle speed measurement system is of utmost importance. It can provide more data references and obtain the optimal driving strategy. Therefore, our team used stm32 microcontroller to develop a set of speed measurement system[9]. Since then, it has played an irreplaceable role in the improvement and debugging of vehicles.

This speed measurement system uses STM32 micro controller as the control core. It not only uses programming software Keil to write relevant processing programs but also connects relevant hardware devices to complete speed measurement through Hall sensors.

Principle: we fix a magnet on the outside of the hub of the prototype car wheel. Then fix the Hall sensor[10] vertically on the plane of the wheel as Fig. 7. When the Hall sensor is energized, the magnetic field changes once every time the wheel rotates once. Therefore, the Hall sensor can sense a change in an electrical signal once. It can be inferred that when the wheel rotates for the second time, the Hall sensor can get another electrical signal again. The difference between the two electrical signal times is the time for one wheel rotation. The circumference of the wheel is displacement, and the time difference is corresponding time. From this, we can calculate the average speed to approximate instantaneous speed.

Fig. 7 Hall sensor mounting location

On the other hand, in order to successfully implement the above principle function, it is necessary to carefully use keil to write programs for stm32. The program mainly uses stm32's library function external interrupt function. The program configures related interrupt service functions and timer functions. When an external signal from a Hall sensor enters, it can trigger an interrupt to start timing. When another signal enters again, it triggers an interrupt again and records the time interval for calculation. In this way, stm32-based speed measurement system can be realized.

2.2 Data Filtering

2.2.1 Hardware Filtering

We found through experiments that when the operating frequency of a single-chip microcomputer is high, adding filter capacitors can greatly improve stability. The filter capacitor should be close to DD end of single-chip microcomputer, and it is best to be connected in parallel with ceramic capacitors and electrolytic capacitors. This involves selecting appro-pirate filter capacitors[11], and selecting capacitors with working voltage that meets circuit requirements as priority; capacitors with large insulation resistance, small dielectric loss and small leakage current are preferred; at same time determine capacitor capacity and allowable deviation according to working environment. We solder-ed a 100nf capacitor between data line connection pin of Hall sensor on industrial control board and ground wire to achieve filtering high-frequency noise effect and complete hardware filtering.

2.2.2 Software Filtering

In terms of software filtering, we mainly screened and corrected erroneous data. The screening process involved both rough screening and fine screening. Rough screening involved discarding data with significant deviations based on empirical methods and normal speed predictions[12]. Fine screening involved creating datasets for the data using reasonable algorithms, replacing the instantaneous instability of individual data with the relative stability of the dataset[13], and outputting mea-surement results with universal stability.

In terms of correction, we used reasonable statistical mathematical models to model the acceleration, decel-eration, and sliding stages separately, and then designed algorithms for correction.

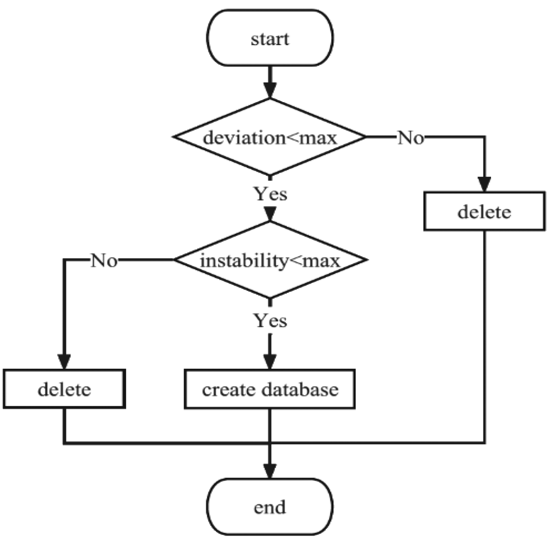

Fig. 8　Filter processing ideas

For different real-time speeds, we adopted different filtering principles as the following flow chart Fig. 9:

When the speed value after debouncing exceeds 30km/h, the time consumed by each wheel rotation should not exceed 200ms, and considering transmission time and other factors, the time limit should be below 400ms. If it exceeds the time limit, there may be a connection problem. At high speeds, there are generally no artificial factors such as braking, and the speed changes are small. When the change exceeds 4km/h, it is considered an erroneous value and corrected.

When the speed value exceeds 15km/h, the time consumed by each wheel rotation should not exceed 400ms, and considering transmission time and other factors, the time limit should be below 800ms. If it exceeds the time limit, there may be a connection problem. At the same time, we introduced the change-Flag to indicate whether the previous value was changed, and the change Speed to indicate the original speed of the previous value. Due to the possibility of significant changes during this acceleration period and the existence of artificial braking, speed measurements are prone to error judgment. Therefore, we have included a correction mechanism. If the previous value was modified and this value still differs significantly from the value modified last time, or if the previous value was not modified and the slope change was not significant, data correction will be performed.

At lower speeds, speed changes may be greater, so any speed change exceeding 20km/h is considered an erroneous data and no longer subject to other restrictions.

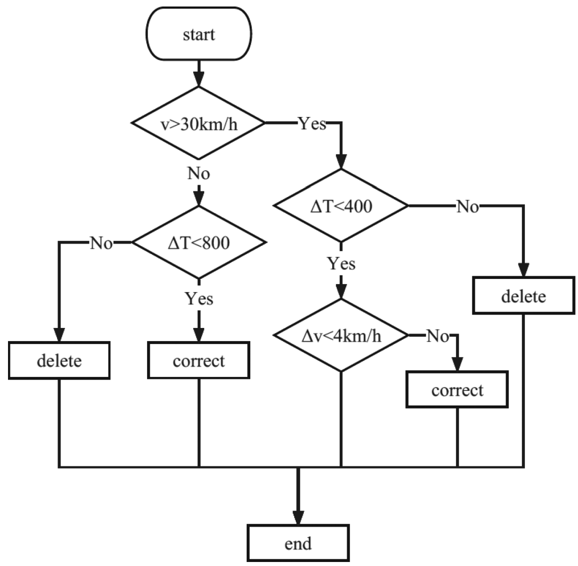

Fig. 9　Speed filtering process

2.3 Automatic timing

Measurement of acceleration and sliding time is important data in daily debugging and preparation for competitions, which serves as a critical basis for optimizing the performance of prototype cars and improving competition results. To improve the large error in manual timing measurement, we designed a system to automatically record accelerated and sliding times.

Firstly, we detect the ignition switch and intake valve switch through the external interrupt function and start or stop timing when the edge changes. In case of triggering ignition switch interruption, we set the custom parameter Start Acc to 1 and start sending signals to the receiving end. After receiving end gets signals, it starts timing and sends feedback signals. In case of triggering feedback signal interruption, we set Start Acc to 0. In other words, it means that the signals will be sent continuously if feedback signals are not received (End Acc is the same).

Secondly, in order to prevent the sending process from being interrupted by input capture interrupt which causes errors in the final spliced binary data, we solder filter capacitors on the circuit board and modify the sending signal to send different values every 500ms. The receiving end determines the starting time based on the received data and retries up to 10 times at most. In addition, in order to solve the issue of timing data based on interrupt function which can't be updated and can only be used once, we use NVIC_System Reset interrupt closing and reset function combined with the clear button on the mobile phone to reset the timing.

However, after completing the above configuration, we encountered a situation where timing and resetting could not be done after 10 attempts of sending signals without receiving feedback. We analyzed that this was because the interrupt of input capture preempted the interrupt priorityof receiving Bluetooth data. When the speed value is high at the end of acceleration, input capture interrupt occurs frequently. Meanwhile, the interrupt of receiving Bluetooth data is a slow serial port interrupt, which is highly likely to be interrupted multiple times and cannot obtain the correct result. Therefore, in the end, we directly set the flag and counter to zero after 10 retries, and reasonably configure the interrupt priority to maintain the normal use of the timing function.

2.4 Speed Transmission Optimization

The transmission of binary speed data in two parts causes delay, increases the burden on the serial port, and increases the interrupt occupation time of input capture. To solve these issues, we propose three optimization schemes with their own advantages and disadvantages that can be adjusted as needed in practical situations.

Scheme 1: With-128 ~ 127 representing the 0 ~ 25.5m/s, the receiving end can obtain the result through the following conversion.

$$v=(data+128)\div 10\times 3.6(km/h) \tag{1}$$

This scheme can represent 0~91.8km/h, which has a wide range. Since the actual demand range is small, some values can be reserved for other purposes (such as sending signals for start/stop acceleration, cruise control signal, etc.). However, the accuracy of 0.1m/s is slightly lower.

Scheme 2: Use Absolute value 0~127 to indicate 0~12.7m/s, and positive numbers indicate trailing numbers 0.05. The receiving end can obtain the result through the following conversion.

$$v=\begin{cases}\left(\dfrac{data}{10}+0.05\right)\times 3.6(data>0)\\ -\dfrac{data}{10}\times 3.6(data\leqslant 0)\end{cases}(km/h) \tag{2}$$

The speed range of this scheme is basically sufficient, and the accuracy is higher than that of scheme 1. However, it is difficult to reserve many values for other purposes.

Scheme 3: Without using parity check, the serial port can be set to transmit 9 bits at a time, and use value-256~255 to indicate 0 ~ 51.1km/h. The receiving end can obtain the result through the following conversion.

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$$v=(data+256)\div 10(km/h) \tag{3}$$

This scheme has the highest accuracy and can reserve some space, but it requires the transmission format of the data, which is difficult to debug.

2.5 Application

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In-vehicle display system is an important medium for conveying driving assistance strategies to drivers. We developed a special mobile APP called Zeal using Java language in the Android Studio environment for the prototype car energy-saving competition. It creates a persistent connection with the server and designs algorithms for receiving, processing, and displaying data.

2.5.1 Basic Functions and Interface Introduction

Fig. 10 is the main interface of the dedicated APP Zeal. The left side of the top toolbar displays the Bluetooth or USB connection status, and the right side includes the Bluetooth connection entry, send-receive mode setting, and system setting. The middle section displays driving time, instantaneous speed, average speed, driving distance, maximum speed, and acceleration count, along with a real-time speedometer and three functional buttons. The "Map" button can display map data obtained from the network or imported racecourse maps in advance; the "record" button can draw a "speed-time" curve based on the received speed data and can correct the speed data according to the algorithm to achieve continuous and smooth speed change trend display. The "clear" button can clear the current measured data and manually reset it.

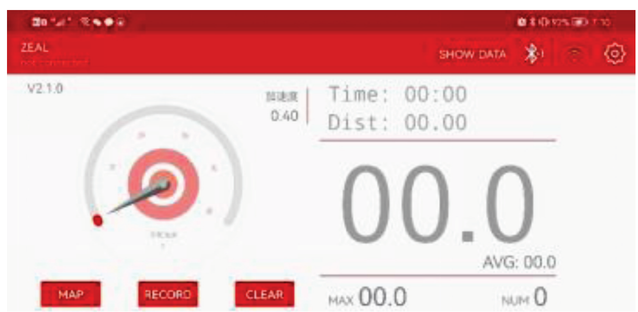

Fig. 10 The main interface of the dedicated APP Zeal

2.5.2 Data Recording

This APP can reserve various parameters such as speed-time, acceleration, distance, and fuel consumption as a single driving data to an Excel spreadsheet for later analysis. Especially in the final stage of preparing for the acceleration strategy, the reserved data can conveniently analyze the time and distance of each acceleration and gliding section, which helps formulate acceleration strategies during the competition.

2.5.3 Bluetooth Automatic Test Program

The APP has an automatic reconnection function for Bluetooth disconnection, which can achieve reconnection within 2-3 seconds after the disconnection. However, if you modify the APP, you need to test it again. Because Bluetooth data is required, you must have the cooperation of the circuit board and Bluetooth. It is difficult to simulate actual situations when not testing driving, and testing is very inconvenient. Therefore, we wrote a program that can simulate sending Bluetooth data to the mobile phone through the serial port operation to simulate the actual driving situation and replay a single driving process.

3 Dynamic Assisted Driving Strategy

An acceleration-coasting cycle driving strategy is adopted by Our prototype car to minimize fuel consumption. The driving strategy used in the race is determined by the team before the race. However, due to unexpected events such as meeting cars, overtaking, or cornering, the driving strategy implemented in the actual race will be quite different from the driving strategy planned before the race[14].

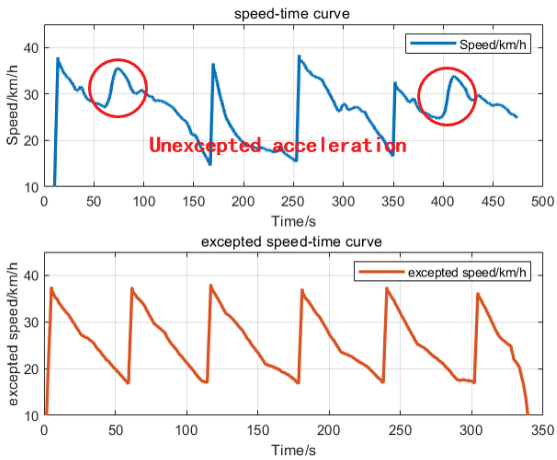

Fig. 11 Unexpected accelerating action

The picture above shows the actual driving strategy adopted by the prototype car driver in the competition in 2019. The red circles show the two abnormal acceleration operations taken by the driver. This abnormal operation deviates from the planned optimal driving strategy, resulting in Vehicle fuel consumption increased by 4.65%, which seriously affected the vehicle fuel economy.

To solve the shortcomings of poor real-time manual planning of driving strategies and the inability to adjust during driving, this paper developed a dynamic driving strategy planning method to regulate the driver's driving behavior through real-time feedback of the optimal driving strategy. So as to achieve the purpose of fuel-saving.

3.1 Physical model of prototype car speed reduction

In order to obtain a suitable dynamic assisted driving strategy, firstly, a vehicle speed reduction model under different working conditions is established to study the characteristics of the vehicle when coasting in neutral[15]. In addition to collecting data from previous races, physical dynamics models are built and Carsim simulations are done in this paper[16].

The resistance F of the energy-saving vehicle when sliding in a straight path without slope and no wind environment is:

$$F = F_f + F_w \tag{4}$$

In the formula, $F_f = Gf_0(1+u_a^2/19400)$ is the rolling resistance; G is the energy-saving vehicle gravity; f_0 is the rolling resistance coefficient, in good asphalt pavement to take $f_0 = 0.014$;

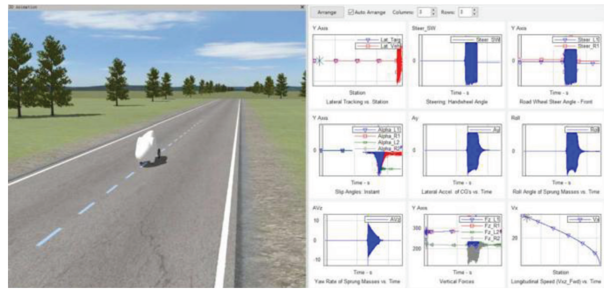

Fig. 12 Carsim Simulation Testing

u_a is the speed of the vehicle; $F_w = C_D A \rho u_a^2/2$ is the air resistance; G_D is the air resistance coefficient; A is the windward area, ρ is the air density.

The acceleration a of an energy-efficient vehicle sliding in a straight path with no slope and no wind environment is:

$$a = -[f_0(1+u_a^2/19400) + C_D A \rho u_a^2/(2G)] \tag{5}$$

We obtained the deceleration curve of the vehicle under different working conditions.

As can be seen from Fig. 13, the smaller the road curvature radius, the more significant the influence of nonlinear factors (e.g., vehicle type, curve curvature radius, speed, etc.) on the speed reduction of energy-efficient vehicles, when the traditional linear speed reduction physical model is no longer suitable for driver-assisted acceleration point prediction. For this reason, this paper proposes a neural network-based information fusion vehicle speed prediction method.

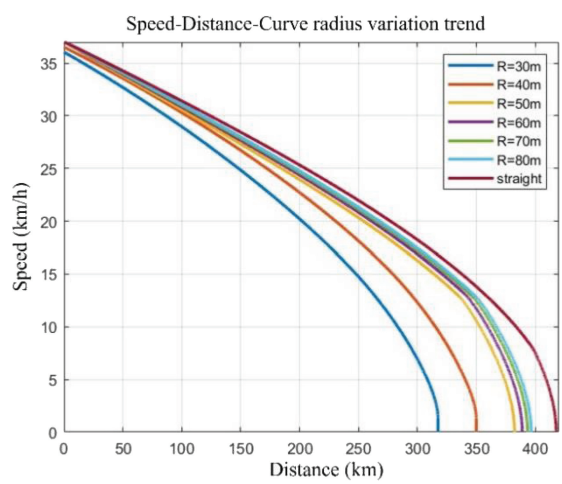

Fig. 13 Deceleration characteristic curve

3.2 Vehicle speed prediction model based on LSTM

In order to predict vehicle speed in real time and provide acceleration point suggestions, this paper considers using Long Short-Term Memory (LSTM)[17] network. The input variables of this model are vehicle speed, acceleration, steering wheel angle, and throttle opening, which include historical information within 5 time steps, and the output variables need to predict the future state. LSTM can control the forgetting or retention of certain information through gate mechanisms, effectively handling the interdependent relationships of information within these 5 time steps, improving the model's generalization ability and prediction accuracy.

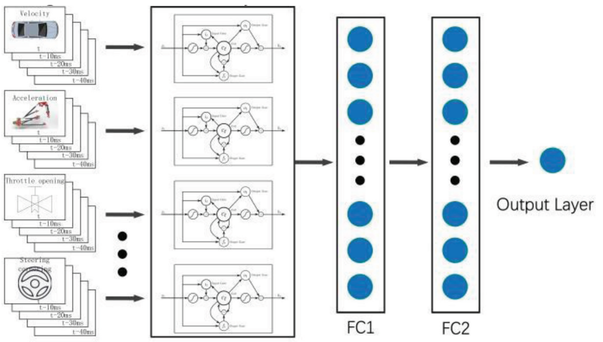

Fig. 14 LSTM Acceleration point prediction model

The neural network model consists of one LSTM hidden layer, two fully connected layers, and each model state utilizes delayed input states within 5 time-steps. Similar to a physical model, this network predicts the optimal acceleration point for a vehicle during deceleration. A seq2seq architecture is used at the top of the LSTM network.

To maximize system response speed, a linear physical model is used on straight aways and a neural network model is used on curves. Therefore, before the race, we divide the track into straight aways and curves, which is the preprocessing of the track data. First, we obtain the geographic coordinates of the path through the API interface of an open map platform.

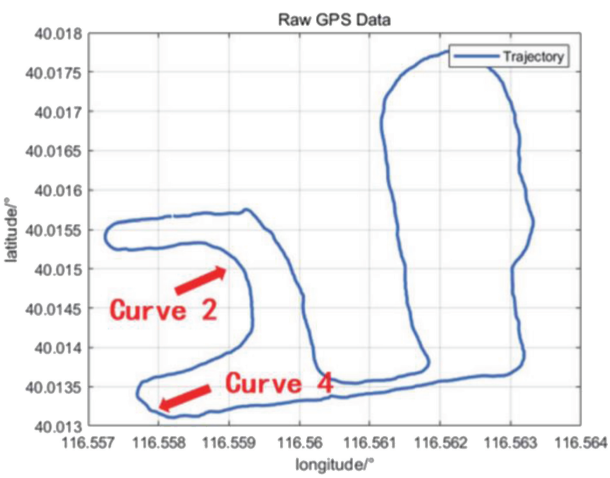

Fig. 15 Course Simulation Map

After annotating the map information, we trained and validated the LSTM network using actual test data from the race car, and optimized the network using a genetic algorithm[18]. First, the length of the genetic algorithm individual coding was determined based on the number of parameters required by the neural network, and the weights and thresholds were encoded as chromosomes. Then, new chromosomes were generated through operations such as selection, crossover, and mutation. Finally, the error function obtained from training was used as the fitness function to evaluate chromosomes, and the chromosome with the highest fitness was selected as the parent of the next generation of chromosomes. The optimized parameters were then assigned to the nodes of the network, which were used for prediction by the optimized neural network.

Through validation, the network $R^2 > 0.999$, indicating good fitting performance and the ability to fully reflect the deceleration characteristics of the prototype car under different conditions.

3.3 Human-computer interaction interface design

To further enhance the user experience and display the driving strategy more intuitively, we developed the human-computer interaction software ZEALGUIDER.

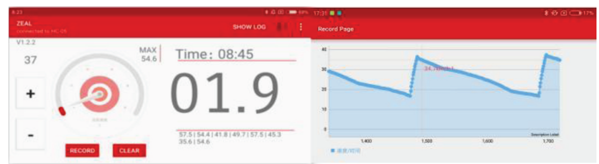

Fig. 16 Zeal interface diagram

Through this software, we can realize the online adjustment of vehicle parameters; the reading, transmission, display, storage, and analysis of vehicle information; driving strategy planning and auxiliary reminder (voice, vibration, optical) functions, greatly improved The degree of vehicle intelligence and further improved fuel economy.

3.4 Experimental results analysis

Based on the above research, in order to further validate the effectiveness of the neural network speed reduction prediction model for the entire road section, experiments were conducted on the EP prototype racing car. Compared with traditional energy-saving vehicles, this car is equipped with human-computer interaction software, GPS sensors, and a 433MHz wireless transmitter used for communication with a computer host. The software can receive, decode, and display vehicle data, and independently develop the best driving strategy.

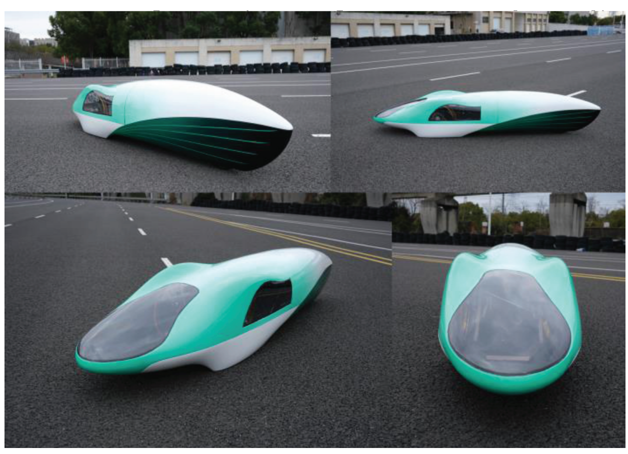

Fig. 17 Experimental Vehicle

During the experiment, a road GPS coordinate map was first established. The vehicle position and speed information were collected by Hall wheel speed sensors and GPS sensors. The 433MHz wireless transmission module was used to communicate with the driver, and the neural network model calculated the distance between the acceleration point and the current position based on the feedback information, and the predicted result was compared with the actual speed reduced to the optimal acceleration value.

LSTM Predict trial results

number	Distance error/m	Error rate/%	Lead time/s
1	0. 21	0. 065	5. 22
2	−0. 30	0. 105	5. 05
3	−0. 58	0. 112	5. 25
4	0. 22	0. 054	5. 21

When the vehicle speed dropped to 25km/h, the vehicle parameters were collected and sent to the host computer for calculation. Accuracy was characterized by the error rate. The experimental results showed that the model could predict the acceleration point position 6. 19 seconds on average in advance, and the single average error rate was less than 0. 1%, with good model calculation performance. At the same time, the distance between the vehicle and the theoretical optimal acceleration point was represented by the high and low frequency of the sound, reminding the driver to take action in a timely manner. The effect of the system was characterized by the number of erroneous operations, which referred to the deviation of the driver's acceleration position from the theoretical optimal acceleration point greater than ±5 meters. After using this system, the average fuel consumption was reduced by 5. 37%.

It should be noted that this method, as a vehicle dynamics analysis method, is not only applied to the case of speed prediction and acceleration point prompt. Because both the vehicle kinematics and dynamics models have many assumptions and simplified conditions, only calculating through physical models will result in some results that cannot meet special conditions, thus magnifying the defects after model equivalence. The results obtained through pure data analysis do not conform to the physical model and cannot be reasonably explained. The integration of physical models and data analysis models can achieve complementary advantages and have broad application value in the field of vehicle kinematics and dynamics.

4 Conclusion

This thesis explores an intelligent assisted driving system based on the actual energy saving needs of EP racing cars. The system includes the development and design of the following three aspects:

1. The development of the electronic control hardware equipment for the EP racing car, including the core board, backplane, wireless communication module and other parts. These modules are the necessary components to realize the basic speed measurement and acceleration point indication. The corresponding electrical wiring simplification scheme is also proposed, which reduces more than 30% of the wiring of the whole car and effectively improves the energy-saving performance of the whole car.

2. Several software developments, including the ZEAL-GUIDER APP, a software system that feeds vehicle information and displays optimal driving strategies. With the 433MHz wireless transmitter module and GPS sensor, the communication delay was reduced to 0. 14s, thus significantly improving the communication efficiency between the driver and the leader.

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