Research on Intelligent Vehicle Platoon Driving Simulation Experiment System under the Coordination between Vehicle and Highway

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Abstract—**Intelligent vehicle platoon driving is a process of the flexible formation based on the coordination between vehicle and highway in the intelligent vehicle-highway system, which can increase the controllability of traffic, simplify the complexity of traffic control, and ease the traffic pressure. It has been constructed that the intelligent vehicle platoon driving simulation experiment system under the coordination between vehicle and highway by means of the one-tenth of model cars, simulated road and the technology about intelligent control and wireless communication. On the basis of the experimental platform and analysis, it has been studied that the autonomous driving technology for intelligent vehicle, and that the information interaction between vehicle and highway as well as that with the main console by the wireless communication networks built, providing the technical and experimental basis for further research on intelligent vehicle platoon driving control under the coordination between vehicle and highway.**

Index Terms—**Intelligent vehicle-highway system; coordination between vehicle and highway; autonomous driving; wireless communication**

I. Introduction

The intelligent vehicle-highway system synthetically considers the traffic condition of different road sections, combining with the communication means, transfers these information resources allocated rationally, balanced and interacted between vehicle sensors and transport infrastructure to the vehicle device for providing drivers with path to be chosen. With the development from the traditional driver-vehicle-road to the intelligent vehicle-highway with all traffic participants as objects, it can improve traffic safety and work efficiency through the intelligent coordination and cooperation between vehicle and highway, and thus ease the traffic pressure [1]. Under the continuous development on information technology, the research emphasis on the intelligent vehicle-highway system has been extended from the early Automated Highway System (AHS) to the focus on the coordination between vehicle and highway. At present, the communication technology between vehicle and highway have more mature in the application for electronic toll collection, and other applications are also under development. Such as the United States' research on Vehicle Infrastructure Integration project (VII), Japan's "smart way" plan, the EU's Cooperative Vehicle-Infrastructure Systems program (CVIS). In our country, the Highway Research Institute, Ministry of Communications, constructs a road test site to carry out the coordination research. Reference [2] proposed a vehicle-to-vehicle and road-to-vehicle collaborative MAC protocol (VRCP), which achieved vehicle-to-vehicle and road-to-vehicle seamless communication through the adaptive selection method about the channel allocation. Reference [3] designed a vehicle-vehicle communication protocol with the goal at the vehicle collision avoidance. Reference [4] studied the wireless communication technology on vehicle monitoring and dispatching, focusing on making a comprehensive comparison between the advantages and disadvantages of various communication means in view of the real-time, safety and reliability on the information delivery.

The intelligent vehicle platoon control system under the coordination between vehicle and highway, emphasizing on the elements of the transportation system, improves the intelligent control of single vehicle and the ability of information interaction with traffic environment, utilizes the master chip to control the direction and speed of vehicles with a small distance in a platoon, so as to realize the platoon driving. Nowadays, however, the theories are not perfect in platoon architecture, behavior characteristics, so are the control algorithm. It is necessary to study intelligent vehicle platoon control by

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the hardware-in-the-loop simulation. Therefore, this article selects DSP as master chip, constructs the intelligent vehicle platoon driving simulation experiment system under the coordination between vehicle and highway, studies the autonomous driving technology by proposing the lateral and longitudinal control strategy; establishes wireless communication networks using ZIGBEE modules and wireless routers to achieve information interaction among vehicles, highway and the main console, which provides the technical and experimental basis for developing the intelligent vehicle-highway system, and achieving intelligent vehicle platoon driving control under the coordination between vehicle and highway.

II. Design of the Intelligent Vehicle platoon driving Simulation experiment System

The intelligent vehicle platoon driving simulation experiment is a process that simulates the vehicle platoon driving and realizes the information interaction between vehicle and highway by the established wireless communication networks. This system consists of three parts: road sand table subsystem, simulation platoon subsystem, the road-side information gathering and monitoring subsystem. The road sand table subsystem, as shown in Fig. 1, consists of 1:10 closed road of 50 square meters and 35 centimeter wide, two lane, which simulates various freeway infrastructure; simulation platoon subsystem consists of 1:10 model cars, vehicle embedded computers, wireless communication modules, vehicle power, speed and acceleration sensors, ultrasonic sensors, digital cameras and so on; and the road-side information gathering and monitoring subsystem include vehicle position detection module, platoon speed measurement module, wireless routers, monitoring server and so on.

Fig. 1 1:10 Road sand table simulation platform

In order to conduct the intelligent vehicle platoon driving simulation experiment, the intelligent vehicle simulation system has been designed, as shown in Fig. 2, including DSP controller, power conversion module, motor drive module (H-bridge circuit), ZIGBEE wireless communication module, CMOS digital camera, infrared obstacle sensors, ultrasonic sensor, and rotary encoder. Lateral information is acquired by using camera and infrared sensors, used to control the actuator; speed of the intelligent vehicle is measured by rotary encoder, distance in the platoon is measured by ultrasonic sensor, information interaction between vehicle and highway is realized by ZIGBEE modules. As the DSP chip adopts the Harvard architecture that separates programs from data, and has a characteristic of the dedicated hardware multiplier, a wealth of on-chip memory and peripherals, pipeline operation, and special instructions, so that it can be used to completing the image processing and complex control algorithms easily.

Fig. 2 Intelligent vehicle simulation system

III. the Autonomous Driving strategy for the Intelligent Vehicle

The study of the autonomous driving for intelligent vehicle has been divided into the research of lateral control and longitudinal control, which is the basic condition for achieving the intelligent vehicle platoon driving. The former mainly studies the recognition and tracking capability of intelligent vehicle, that is, how to control it driving along the road lane markings; the latter focuses on the wheel speed control, so that it drive stable on the road sand table. Nowadays, home and abroad, the control method of the single vehicle is more mature [5-7]. Therefore, the autonomous driving strategy for the intelligent vehicle, around the platform and the system, mainly studies the relationship between the pulse duty cycle for controlling actuator and the position of road lane markings, and that between the pulse duty cycle for controlling motor and the wheel speed, as well as the relationship between the factors mentioned above.

A. Lateral Control

According to the road reference information as shown in Fig. 3, the intelligent vehicle simulation system sets up the tracking and obstacle avoidance strategies mainly based on CMOS digital camera with infrared sensors assisted to avoid obstacles. The infrared sensors, installed on the front of the vehicle, are used to detect roadbed; digital camera is used to detect only the left lane of the road markings. Thus, the controller does not store and process a large amount of data, so as to make the control algorithm more effective. In addition, As there have been some problems under different road conditions, such as tunnels, big bend, and the shadow of the road, which results in tracking road lane markings hardly, the infrared sensors have been introduced to auxiliary optimize the lateral control strategy. The connection between CMOS digital camera OV6620 and DSP controller is simple, as CMOS digital camera is with 5 V power supply and DSP controller is with 3.3 V power supply, there has been added a 3.3 V to 5 V level converter chip between them. The 1-8 pins of Ov6620 chip output the 8-bit gray-level signal; 14 pin outputs line interrupt signal; 16 pin outputs field interrupt signal and 18 pin outputs pixel sync signal.

The field interrupt signal is to determine whether an image is started, the line interrupt signal is to determine whether the beginning of the image, the pixel sync signal is to determine the validity of the gray value. The CMOS digital camera collects a frame of image and determines the ranks of each frame, that is, the number of pixels point. On the acquisition of the video data back, there should be image binary and noise processing, then the extraction of the center line of the left road lane marking. At the end of an image processing, according to the slope of the center line and the offset from the longitudinal axis of the vehicle to determine the current road information, combining with obstacle information measured by the infrared sensors, control the actuator. The strategy is shown in Fig. 4.

Fig. 3 The road reference information

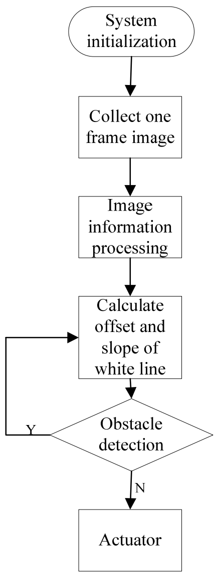

Fig. 4 The lateral control strategy of the intelligent vehicle

B. Longitudinal Control

To realize intelligent vehicle platoon driving, the key is the platoon control method, and the core issue is the stability of the platoon [8]. The stability of the platoon refers that the speed fluctuation and the fluctuation of distance between vehicles in the platoon will be magnified and spread, resulting in oscillation of the platoon, which has become increasingly significant with the increase in the number of vehicles. To solve this problem, it is usual to obtain more accurate information about control links or to introduce advanced intelligent control method. Thus, the longitudinal control of the single vehicle is the basis for the platoon. In addition, the road sand table is big, rough (slightly higher than sandpaper), and complex with less straight, more bend and a very steep tunnel. These factors require not only the longitudinal control algorithm can adjust the speed quickly and stably, but also the hardware requirements of the intelligent vehicle simulation system, especially the motor drive circuit, are able to adapt the complex conditions, and provide the intelligent vehicle with the sustained and strong power. Here, it is designed that the H type full-bridge circuit with current detection, as shown in Fig. 5, the upper half of which is the H bridge circuit composed of MOSFET, transistors and freewheeling diodes; the lower half of which is the current detection circuit composed of high-power resistors and operational amplifier to detect the armature current of the motor. This circuit, together with the speed measurement link, can construct the control system of speed and current double closed loop, which can reduce the battery discharge, improve the anti-interference ability of the speed control links.

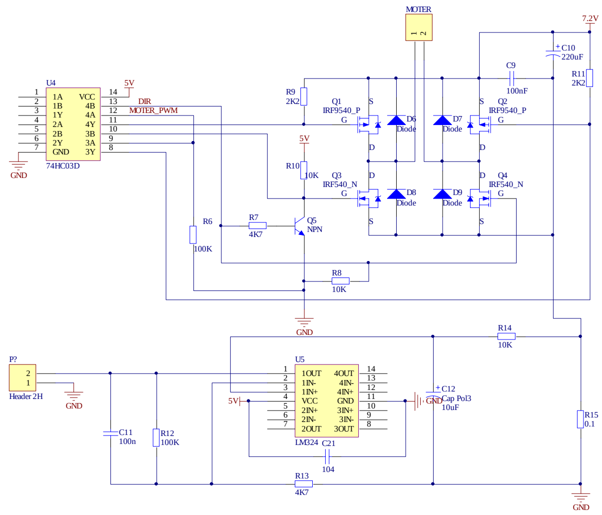

Fig. 5 The H type full-bridge circuit with current detection

In the intelligent vehicle platoon driving, ultrasonic sensors have been added to detect distance between vehicles. The measurement range of ultrasonic sensor, URM37V3.2, is from 4 centimeter to 500 centimeter. Its output mode can choose Pulse Width Modulation (PWM). After observation from the oscilloscopes and calculation, 4 centimeter in distance corresponds to the 2.6 millisecond in cycle of PWM, and every 1 centimeter increases or decreases corresponding to 0.1 milliseconds. Therefore, the relationship established between the distance x and the cycle t is:

$$t = 2.6 + 0.1 * (x - 4) \quad (1)$$

In this way, the distance is calculated by (1). The longitudinal control diagram of the intelligent vehicle is shown in Fig. 6.

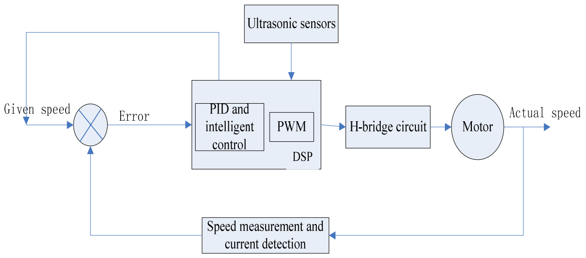

Fig. 6 The lateral control strategy of the intelligent vehicle

Ⅳ. INFORMATION INTERACTION BETWEEN VEHICLE AND HIGHWAY

The architecture of intelligent vehicle platoon driving simulation experiment system is a bottom-up hybrid hierarchical structure, including the controlling layer of platoon driving behavior, the planning layer of the coordination between vehicle and highway, and the monitoring layer of transport system, respectively, As shown in Fig. 7. The controlling layer is the ground floor, connecting closely with the roads and environment, is also the most important one which includes road and environmental awareness, mission plan, decision-making behavior and vehicle operation, the planning layer collects the information coming from the controlling layer, and hands on it to the monitoring layer, meanwhile, transfers the information released by the monitoring layer to the controlling layer, so it is the coordinator in the architecture, the monitoring layer plays the role of macro-control, summaries the information sent from the planning layer, analyzes and processes them, then send the result to the planning layer. Therefore, the wireless communications system played a crucial role in the architecture. With the development of wireless mobile network technology and wireless sensor network technology recently, there have enough technical support for realizing the information interaction between vehicle and highway [9-11]. The process of the information interaction between vehicle and highway in the intelligent vehicle platoon driving simulation system is as shown in Fig. 8.

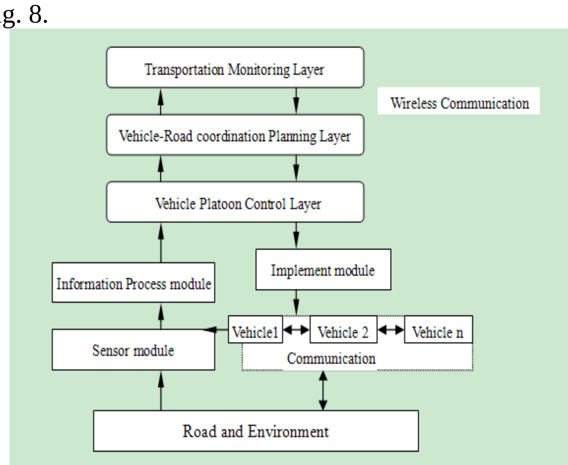

Fig. 7 The architecture of intelligent vehicle platoon driving simulation system

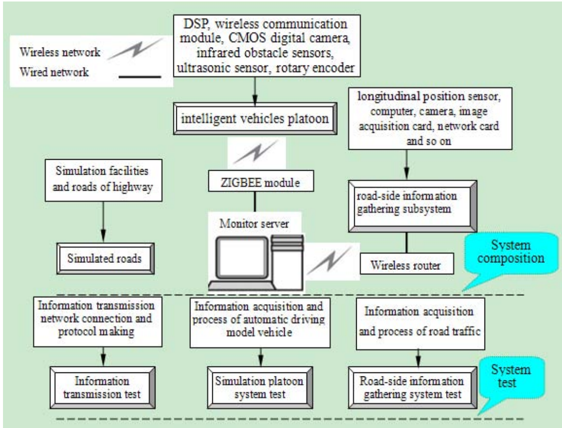

Fig. 8 The process of information interaction between vehicle and highway

A. Vehicle-Vehicle Communication

Intelligent vehicles achieve the data communication between each other by ZIGBEE modules. ZIGBEE modules connect DSP controller with a host computer through the serial communication, setting up a wireless communication networks. ZIGBEE modules can set network flexibly by themselves without manual intervention, the network nodes can perceive other nodes and determine connection mode, the wireless frequency used in the whole network is free internationally from 2. 4 to 2. 48 GHz, the transmission mode uses the direct sequence spread spectrum with a strong anti-interference ability. Actually, in the design, it has been selected that the wireless transceiver chip, MC13124, that contains a standard IEEE 802.15.4 physical layer, which makes the wireless network supporting peer-to-peer network, mesh networks, star network and tree network. As there have three types of ZIGBEE communication nodes: central node, relay route, terminal node, the lead intelligent vehicle need to be set as central node firstly, and other vehicles are set as relay route with different ID numbers. Secondly, the serial baud rate is set 9600 bit per second, thus all of the ZIGBEE modules are with the same letter 0x0F, that is, 2.480GHz. Finally, the transmission and receive mode chooses the mode based on destination address. As a result, the system sends the packets of different ID number to achieve the vehicle–vehicle wireless communication. On this basis and considering the accuracy of data transmission and receive, the data format are as follow:

TABLE I.
DATA FORMAT

Start frame flag	Identifier field	Data field	End frame flag

Where, the start frame flag is the ID number of the intelligent vehicles, the hexadecimal FF denotes the end frame flag. The length of identifier is one byte (8 data bits), consisting of a 4-bit identifier type field and a 4-bit check field. Identifier type field include speed, accelerator, steering, location and spacing, and so on; check field detect the errors of identifier type field through generating the anti-code of each bit of identifier type field, ensuring the reliability of identifier decoding. Data field contains a hexadecimal number, high bit in the front and low bit in the post. According to the data types of identifier field, the corresponding values can be obtained from data fields, which ensure the accuracy of sending and receiving. The flow chart of sender and receiver is as shown in Fig. 9.

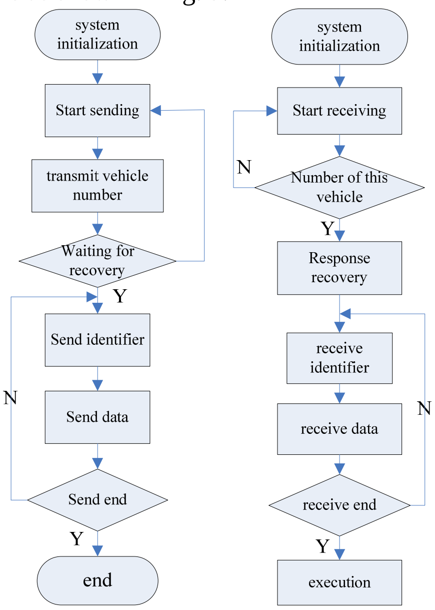

Fig. 9 The flow chart for sender and receiver

B. Vehicle-Road Communication

The road-side information gathering subsystem, through the road-side sensors system, receives the information about intelligent vehicle platoon, and transmits it to the monitoring center by wireless routers for data communication, adopting network Socket programming. It's best to choose UDP protocol to send and receive data in the local area network. When programming for the sending, the first step is to load socket library, followed by creating and initializing the socket, attention must be paid before sending, binding socket in advance. The receiving program, as the same with the sending, must be set to the same port, otherwise data receive will be failed. The program is divided into two parts:

The first part of server-side

- the creation of server-side socket(create);
- server-side socket bind information(bind), and begin to monitor connection(listen);
- accept connection from the client request(accept);
- the beginning of data transmission(send / receive);
- close socket (close socket).

The second part of the client

- create a client socket(create);
- connections with server-side(connect), when accepted and then create the receiving process;
- the beginning of data reception(send / receive);
- close socket (close socket).

It's necessary for the system to achieve information interaction between vehicle platoon and the road-side information gathering and monitoring system, and is also an important foundation to realize the intelligent vehicle platoon driving. So, the software of the information interaction between vehicle and highway has been designed, as shown in Fig. 10, using the MSCOMM in Visual C + +, according to the agreement and forms of ZIGBEE modules and wireless routers. Not only can it obtain and store vehicles information about different road condition, but also communicating with the different road-side information gathering and monitoring stations by setting the IP address.

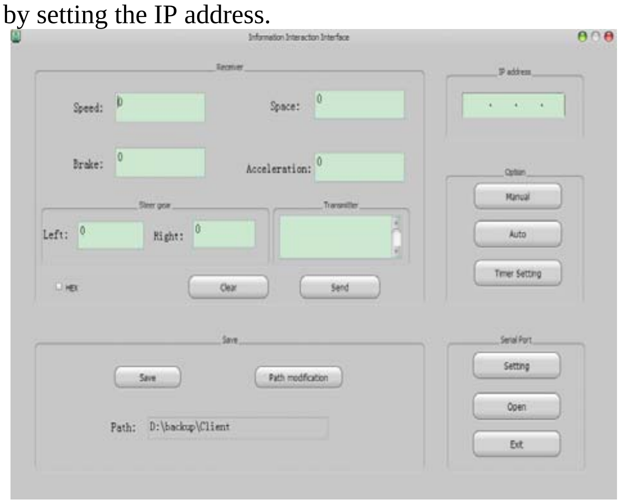

Fig. 10 The information interaction interface between road and vehicle

Ⅴ. EXPERIMENTAL ANALYSIS

A. Experimental Analysis of the Actuator of the intelligent vehicle

Since the lateral control strategy for the intelligent vehicle adopts the combination of digital camera and infrared sensors to avoid obstacles, in view of that the output of the infrared sensor is switch signal, there only have to build up the correct logical relationship and set up different priority in the program. But the key of the strategy is the stable image processing algorithms. Here, after the analysis on the binary image processing, the noise processing and the extraction of the center line of the left road lane marking, then the algorithm for controlling the actuator is proposed.

1) image binary processing.

First choose a reasonable threshold, which in this experiment is on the basis that before the intelligent vehicle driving, acquire a total of six fields of the image on the road sand table, considering the instability of the first field, from the beginning of the second field, compute a maximum value of every row in every field, then to compute the average of these maximum values of the five fields, which will be the threshold of each row after integral compensation. Repeatedly testing, the compensation value selects -7. The formula of the threshold η is:

$$\eta_j = \left(\sum_{i=2}^{6} a_{ij\,\max} \right) \Big/ 5 + C \qquad (2)$$

Where

$a_{ij\max}$ is the maximum value at the i field and j row of the image,

C is the compensation value,

η_j is the threshold of each row.

The function for image binary is as follow:

$$f(x,y)=\begin{cases}1 & p(x,y)>\eta_j \\ 0 & p(x,y)<\eta_j\end{cases} \tag{3}$$

Where, $p(x,y)$ is the original data, $f(x,y)$ is the binary data.

2) image binary processing.

As the digital camera has large influence for the surroundings, after image binary, the image also have a number of noise interference besides path information. In order to reproduce the true path information, it must be carried out noise processing to accurately calculate the center line of the road lane marking. Here, the basis for noise processing is that a row of image data, as nearest as the intelligent vehicle, is taken as the base line after noise processing for itself. The process is as follow:

a) To determine the location of the first row whether meets the conditions given or not. That is, the number of white points is more than one. if only one point is white, it will be the noise, and put 1 into 0, then continuing determining the location of next row. If the white line points are more than the number of a given calibration value, it is considered to detect the pavement.

b) To determine the continuity of white points. That is, the deviation of the initial location of white point in the first row, compared with that in last row of last field, is within normal limits. According to the continuity of image, the deviation should not be too great, if it excesses a given calibration value, it will be the noise, and put 1 into 0, then continuing determining the location of next row.

After dealing with the data of the base line and putting it as reference data, according to the continuity of image, there should be noise processing for the entire field of image. The effect of an image data before and after noise processing is as shown in Fig. 11.

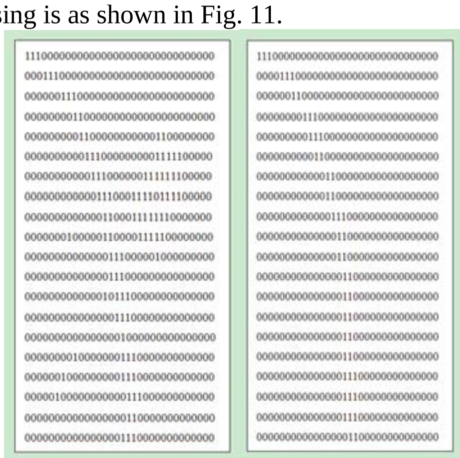

Fig. 11 The effect of an image data before and after noise processing

3) extraction of the center line of the left road lane marking.

After an image processing, there are the true path information about road sand table. Only calculating the center line of the left road lane marking, is it carried out the path analysis and experiment on controlling the actuator. Meeting the two conditions above, it is the white line. The center position of the white line can be derived by (4):

$$Center = i + j/2 \tag{4}$$

Where, i is the initial location of the white lines, j is the total number of the white points.

According to the center line composed of the centers of each row in the image, whose slope and offset from the longitudinal axis of the vehicle can determine whether the current road is straight or turn. The control variable of actuator can be given by these parameters. The formula is:

$$\mathrm{U} = K0 * |X0| + K1 * (Y1 - Y0)/(X1 - X0) \tag{5}$$

Where,

U is the variable of controlling actuator;

(X0, Y0) is the center coordinate of the white line in the last effective in the image data;

(X1, Y1) is the center coordinate of the white line in the first effective row in the image data;

|X0| is offset of the coordinate (X0, Y0) in the lateral axis;

(Y1-Y0)/(X1-X0) is the slope of the center line of the left road lane marking;

K0 and K1 are the proportional coefficients, which are derived by experience and debug.

B. PID Control

As the analysis on the longitudinal control puts it, it is usual to obtain more accurate information about control links or to introduce advanced intelligent control method to solve the problem about the stability of platoon, in particular, the stability of the speed. At present, the control theory and control technology, under the rapid development of the information technology and the integrated circuit manufacturing technology, make a significant progress [12]. For example, the improved PID algorithm, adaptive control, neural networks and fuzzy control, robust control, sliding mode control and optimal control, as well as many other modern control algorithms have been widely used. However, the PID control is still a stable, reliable, and simple control method.

The digital PID control method uses numerical approximation to achieve the PID control law. When a very short sampling period, sum instead of integral, and the latter difference instead of the differential. Formula is:

$$u(k) = K_P e(k) + K_I \sum_{i=0}^{k} e(i) + K_D (e(k) - e(k-1)) \tag{6}$$

Where, K_P, K_I, K_D are proportional, integral and differential coefficient, k is the sample number.

The control algorithm adopts the incremental control algorithm which need not compute the cumulative error, only to obtain an incremental amount of control variables that has only to do with the recent sampling value of error. Thus, the disoperation has little impact on the control system, and the integral links will not be out of control. Formula is:

$$\begin{cases} u(k) = u(k-1) + \Delta u(k) \\ \Delta u(k) = K_P(e(k) - e(k-1)) + K_I e(k) + K_D(e(k) - 2e(k-1) + e(k-2)) \end{cases} \tag{7}$$

The controller uses PID control method, it is only to build the relationship between the wheel speed and pulse duty cycle for controlling the motor to make the sampling and analysis for the error, without considering how to establish the model of control object, that is, the motor. Fig. 12 demonstrates the fitting curve compared with the actual curve of the wheel speed. Base on this, the relationship between the wheel speed and pulse duty cycle has been built.

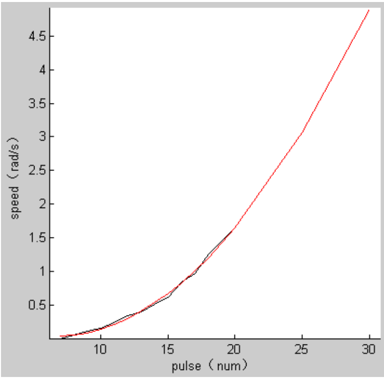

Fig. 12 The fitting curve of the wheel speed

In the Fig. 12, the lateral axis denotes the pulses with a certain cycle and different duty cycle, the longitudinal axis denotes the wheel speed under different duty cycle, the black curve is the actual curve of the wheel speed, the red curve is the curve fit by the least squares method using the MATLAB.

The Fig. 13 show the speed response curve of the intelligent vehicle with the digital incremental PID control algorithm, under the road condition from flat road to the uphill. Here, K_P is 2, K_I is 1, and K_D is 0.01. The data is received and saved by the information interaction software shown in Fig. 10.

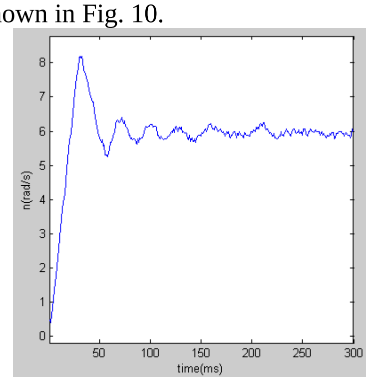

Fig. 13 The speed response curve of the intelligent vehicle

Seen from Figure 13, using digital incremental PID control algorithm is more effective. The overshoot output by controller is small, and the convergence is fast, which meets the stability of requirements and technical performance of the intelligent vehicle. However, the motor itself has a characteristic of small time constant, fast dynamic response, small inertial and easy introduction of interference, when motor is going to the steady-state under the control of the digital PID control, due to the existence of outside interference, there is always a slight jitter of the speed.

C. Design of the Main Console Control Software Interface

In order to improve the intelligent control level of the single vehicle, as well as the ability of the information interaction between vehicle and highway, the control software interface of the main console based on wireless communications by the ZIGBEE module has been designed, as shown in Fig. 14, also using the MSCOMM in Visual C + +. The software can be used for intelligent control for the single vehicle, and also be used for stop-and-go control, sequence control for double intelligent vehicles, at the same time, receiving the speed, steering, location and other information about intelligent vehicles, which is easy to adjust control strategies online, store data and analyze date.

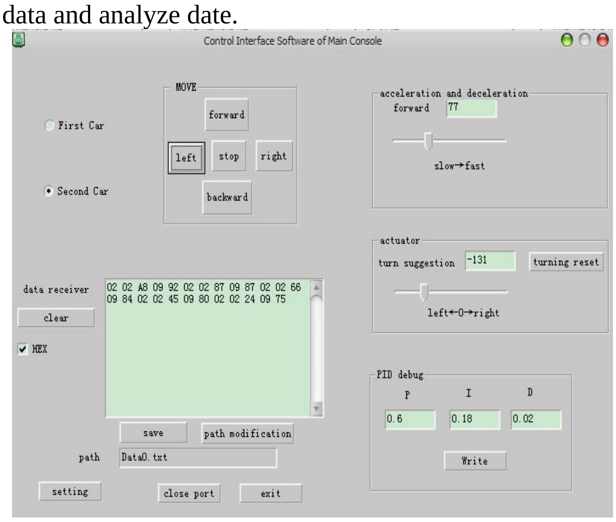

Fig. 14 The interface software of the main console control

VI. Conclusion and Prospect

Intelligent vehicle platoon control under the intelligent vehicle-highway system is one of the hotspots in recent research field of the intelligent transportation, where the hardware-in-the-loop simulation technology is an important means. In this paper, the intelligent vehicle platoon driving simulation experiment system is built, and the system composition and the function of each part are described. It has been proposed the autonomous driving control strategy for the intelligent vehicle, which is analyzed and proved through the experiment, and it is also designed the wireless communication networks by ZIGBEE modules for the information interaction between vehicle and highway, providing the technical and experimental basis for further research on vehicle platoon driving control under the coordination between vehicle and highway.

The next work is as follows:

- In the lateral control, the image processing algorithm continues to be improved, landmark recognition will be chosen to navigate, rather than a special road lane markings;
- In the longitudinal control, a simple, accurate vehicle dynamics model still needs to be pursued, and the smart and efficient control method needs to be found;
- In the information delivery, improving the instability and delay of wireless networks to obtain more real-time, accurate information in order to support the platoon driving;
- In vehicle platoon control, the formation control of the platoon should be studied, the stability conditions of the platoon continue to be analyzed, and the high-fault-tolerant control algorithm for the platoon is going to be explored.

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