Research and Development of Automatic Driving System for Intelligent Vehicles

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Abstract An innovative universal automatic driving system for intelligent vehicles is designed in this research. With a few mechanical modifications of four subsystems, i.e., steering system, breaking system, throttle system, and gearing system of the original manned vehicles, and the installation of an automatic control device, this system is finally established by connecting each subsystem and upper computer via CAN bus. It is proved by vehicle tests that upper computer can precisely control the underlying subsystem through automatic driving system, and this system can be used not only for vehicle bench test, but also for automatic driving of intelligent vehicles, which establishes a foundation for further researches of unmanned and intelligent control of vehicles.

Keywords Intelligent vehicle · Versatility · Automatic driving · Steering control

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1 Introduction

The perception technology is important for the intelligent vehicle development, and the machine vision is the most important part of the intelligent vehicle environment perceptual system [1, 2]. Along with the development of theories and technologies of vision, artificial intelligence, and automatic control, more and more intelligent algorithms are designed which are more effective than before to improve the ability of intelligent vehicles to be intelligent controlled continuously, and the development also promotes the intelligent vehicle from remote control to semi-autonomous control and fully autonomous control [3]. In the process of the development of intelligent vehicle, the performance of underlying automatic driving system is always a key factor which will influence the vehicle's intelligent control ability. The automatic driving system can receive instructions from the upper computer, and control the vehicle's movement parameters, such as the states of steering, speed, and gearing. As the ultimate executive of all motions, the effectiveness of the automatic driving system has a direct effect on the performance of the intelligent vehicle, e.g., whether it can complete the upper computer instructions accurately and timely. The automatic driving system is therefore the foundation of the intelligent vehicle's capabilities including perception, planning, reasoning and decision-making, and so on, and is also one of the core systems of the intelligent vehicles [4, 5].

Traditional automatic driving system consists of steering system, breaking system, throttle system, and gearing system, and controls vehicles through adding a series of complex mechanical systems such as motor, gear reducer, machinery to the original manned vehicles. The automatic driving system of the ABD Company of the United Kingdom is mainly used in vehicle tests but only applies to limited vehicle types. The automatic driving system developed by the Kairos Company of the U.S. is mainly used in the modification of the intelligent vehicles, but its steering precision is not satisfactory, and transmission is not stable. The automatic driving systems developed by the Staler of German and the Horibo of Japan have the ability to control vehicles, but not in real-time, and can only be used for vehicle bench tests. The automatic driving system for "Intelligent Pioneer" developed by the Institute of Advanced Manufacturing Technology of Chinese Academy of Science is based on the mechanical structure of the original manned vehicle with extensive modifications and is prone to adversely impact the performance of the original manned vehicle. Faced with many problems that exist in the automatic driving system, this research is to explore and achieve a more rational design of an automatic driving system [6–8].

2 Overall Scheme

In order to enable the intelligent vehicle to complete a variety of independent actions in a complex environment, a layered architecture including the perception-planning layer, execution layer, and so on, is designed. The perception-planning layer produces intelligent planning and motion instructions. The major components of the perception-planning layer include the visual perception equipment and the upper computer. Based on the expectations of motion instructions, the execution layer controls underlying actuator action. The execution layer is mainly composed of the automatic control system and its corresponding execution subsystems.

The automatic driving system requires for the perception-planning to make perception-planning decision every 100 ms time and produce a movement instruction set, which includes the expectations of steering angle, the throttle opening, the braking amount, and the gearing position. (This requires the execution layer within 100 ms should quickly and accurately perceive the perception-planning layer planning expectations.) In order to achieve this goal the original manned vehicle needs necessary mechanical modifications and automatic control devices during the process of designing the execution layer. By these modifications, the original manned vehicle is transformed into an intelligent vehicle. The intelligent vehicle can receive steering, speed, braking, and other instructions and perform the corresponding action through the automatic driving system. The design of the automatic driving system should meet the following requirements:

- Control precision and reaction time of the execution layer, provided by the perception-planning layer.
- The mechanical modifications of the original manned vehicle should be minimum.
- The performance of the original manned vehicle should not be affected.
- Maintaining high versatility, reliability, and stability.

The overall scheme of the automatic driving system is shown in Fig. 1. It can get vehicle location information and speed information through the GPS equipment, wheel speed sensors, or other sensing equipment. Through the trajectory generator it can get vehicle intended trajectory information. Trajectory generator calculates the position and velocity requirements of the preview points. The lateral controller and longitudinal controller complete the calculation of the control parameters. The direction control and speed control parameters of the vehicle will be sent to execution system by the multiplexer. In this way, automatic driving system controls the vehicle running according to a predefined trajectory. The main function of each module is as follows:

- Input modules: the connection of the GPS device, wheel speed sensors, or other sensing equipment to determine the location and other status of the vehicle.
- Control module: mainly responsible for seeking a preview point in the predefined trajectory and calculate control parameters. The calculation parameters are sent via CAN bus.
- Output modules: the connection between control and execution system, including the steering control output, braking control output, throttle control output, and gearing control output.
- Other expansion modules: a light and horn control, and ignition control by relays of the vehicle.

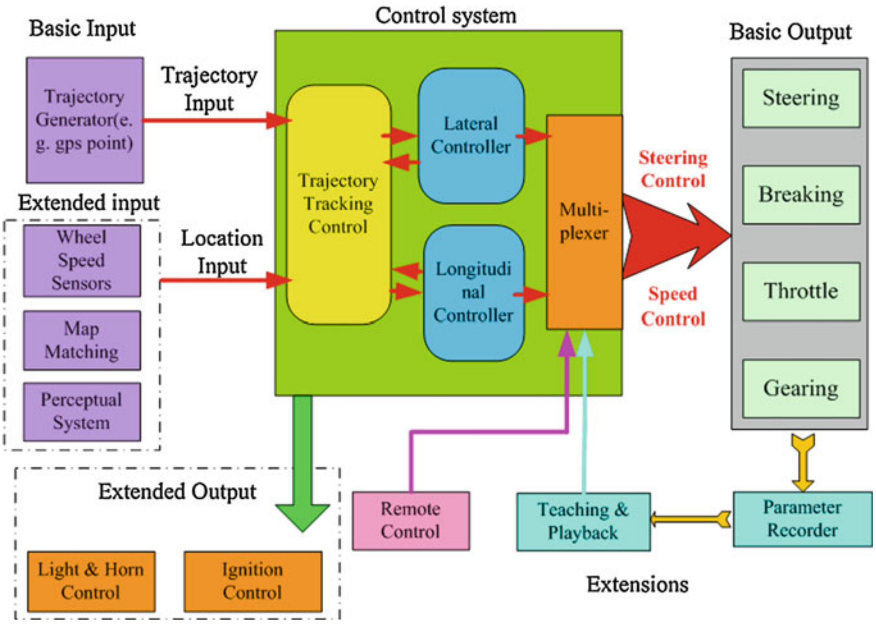

Fig. 1 The overall scheme of the automatic driving system

3 Control System

3.1 Controller Hardware

The Freescale MCS12XDP512MAL microcontroller shown in Fig. 2 is the core component of the automatic driving system, which can let external auxiliary circuits control the execution system. Finally, the automatic driving function is achieved. The entire system includes a serial communication module (SCI), a CAN bus module (MSCAN12), a timer module, an SPI bus module, a PWM module, and a co-processor module (XGATE) [9]. The main function of each module is as follows:

- The serial communication module (SCI) communicates with the onboard GPS device (CPT) to receive GPS data.
- CAN bus module (MSCAN12), divided into two CAN bus modules which are called CAN0 and CAN4. CAN0 bus module communicates with the upper track sending system, receiver trajectory path and sends the vehicle status information (GPS position, speed, and heading) to the upper computer; In addition, the upper computer can also send control mode instructions to specify the controller a machine mode (trajectory tracking mode, the path acquisition mode, the direct control mode, and the implementation of the system back to the zero mode);

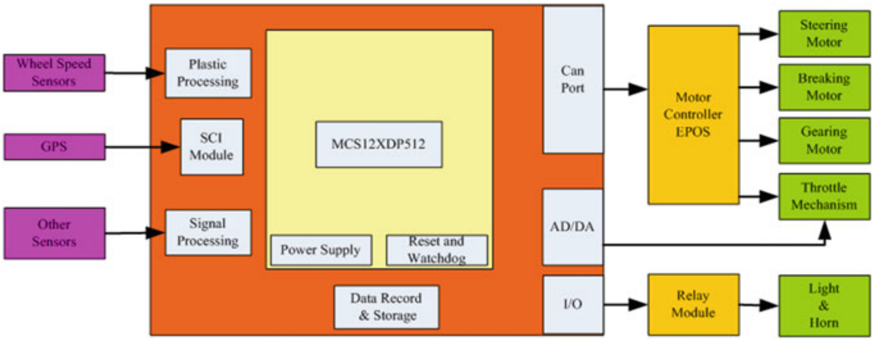

Fig. 2 Controller hardware system block diagram

CAN4 bus module communicates with motor controller, outputs the motor control parameters.

- Timer module is used for regularly scanning the keyboard operation and interrupt management of other modules.
- SPI bus module, used for the data storage device (SD card).
- PWM module, used for the buzzer and wheel speed encoder control.
- Co-processor module (XGATE) separately deal with the CAN0 interrupted trajectory path data, reducing the data processing time of the system.

3.2 Controller Software

The controller software shown in Fig. 3 is the core of the automatic driving system. The main function performed by the controller software is as follows:

- To receive GPS signal every 100 ms, parse out the vehicle's current position, velocity, and heading information.
- To receive the path trajectory points sent by the upper computer, and then parse and store the information.
- To find the preview points based on the vehicle's current position and intended track.
- To calculate the vehicle's lateral control and longitudinal control parameters based on the preview points.
- To control the execution system by calculating the lateral control and longitudinal control parameters, outputs control instructions.
- To record and store the driving status information in a real-time manner.

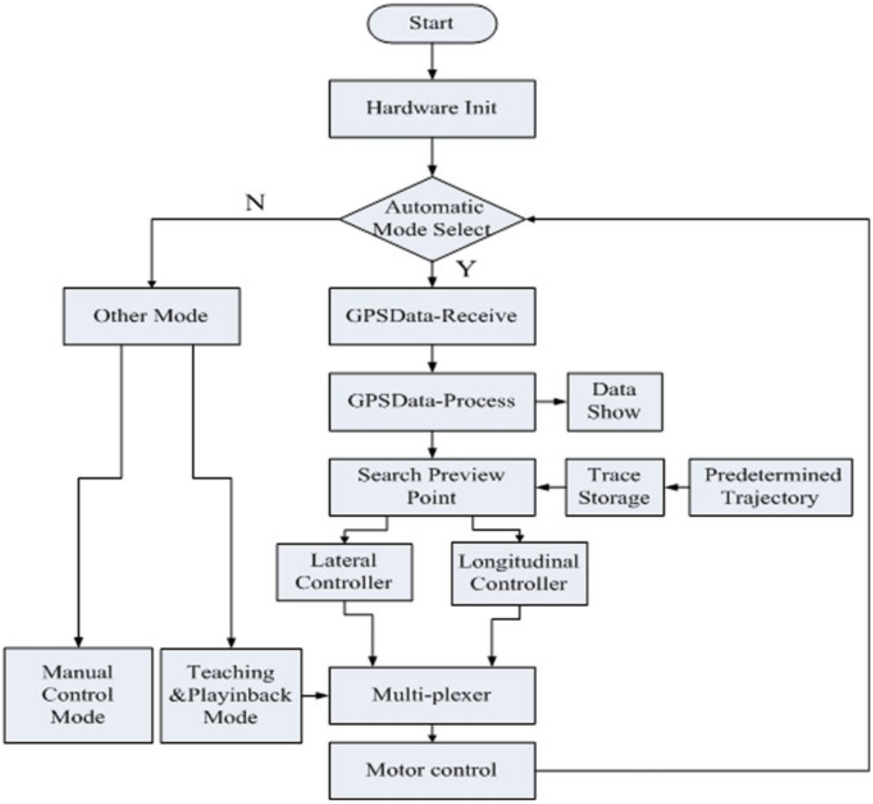

Fig. 3 Control software flowchart

4 Execution System

In order to simplify the installation process and maximize the versatility of the system, a method of modular design is adopted in the development of the execution system. The execution system shown in Fig. 4 consists of four subsystems, i.e., steering system, breaking system,throttle system, and gearing system [10].

The steering system shown in Fig. 5 with synchronous belt transmission is directly installed on the steering wheel in order to make full use of interior space and minimize the influence on the manual driving mode as much as possible owing to the automatic driving system. In this way, the steering system can be installed in many different vehicles with high steering control precision, which mainly consists of DC servo motor, gear reducer, electromagnetic clutch, synchronous belt and encoder, etc.

Sharing a similar mechanical structure, the breaking, throttle, and gearing systems shown in Fig. 5 utilize a flexible shaft with certain flexibility. The three subsystems use DC servo motors to drive ball screws and then pull the flexible

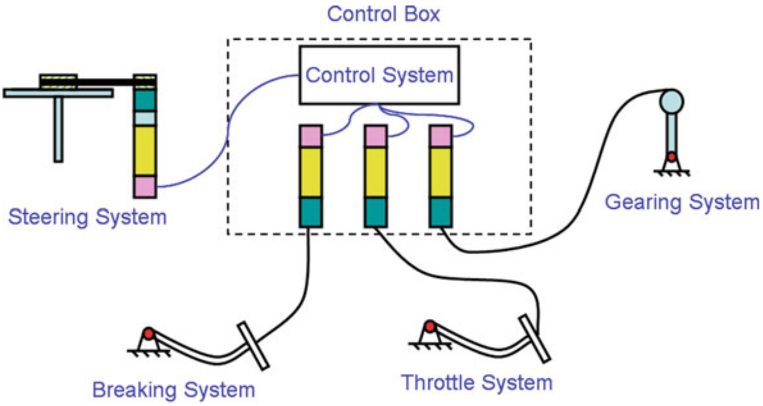

Fig. 4 Schematic diagram of the execution system

Fig. 5 The execution system

shafts. Different specifications of the flexible shafts are connected to the brake pedal, the gas pedal, and the gear knob, which are in different states by controlling of flexible shaft in different positions in order to achieve speed and gearing control of the intelligent vehicles. The three subsystems consist of DC servo motors, ball screw, flexible shafts and encoders, etc., whose main parts are integrated in the control box. In this way, not only the easiness of the installation of the three subsystems and the versatility of the system are guaranteed, but the functional independence between the manual driving and automatic driving modes is secured.

5 Vehicle Tests

In order to ensure the relative independence of the vehicle test, cameras, laser radars, and other sensing equipments are not used to generate path trajectories in real-time. Instead, the vehicle positioning device (SPAN-CPT) is used to pre-collect trajectory data set, including the track point position information and velocity information. Once track data is loaded, the upper computer sends the planned track data to the control system via CAN bus. Based on the track data and

Fig. 6 Test track of the vehicle

the position and speed information, the control system tracks the position and speed of the vehicle, provides both lateral and longitudinal control parameters, and finally completes the automatic driving of the vehicle on a predetermined path. Figure 6 depicts the test track of the vehicle and the straight path is about 300 m, the curves are about 1,200 m, and the total length is about 1,500 m.

Under the automatic driving mode, SD card records part of the vehicle track data, including latitudes, longitudes, headings, and speed information. See Table 1 for details.

Lateral control test consists of the straight line test and curve test. In the process of straight line test, the average speed is set to four kinds of circumstances, i.e., low speed (15 km/h), medium speed 1 (35 km/h), medium speed 2 (50 km/h), and high speed (80 km/h) to test the lateral control precision of vehicle in all kinds of

Table 1 Part of the data about SD card record

Latitude	Longitude	Heading (North declination)	Speed (m/s)
31.818923132	117.128479713	178.772528514	0.11895
31.818923568	117.128481080	178.794638984	0.12886
31.818896904	117.128473439	176.253454441	2.00286
31.818895079	117.128473596	176.112071448	2.05744
31.818829588	117.128480760	174.201816601	3.04548
31.818806946	117.128483148	174.863372476	3.24682
31.818173316	117.128494761	179.417047024	5.06178
31.815174147	117.128522499	178.052994253	8.04338
31.812290068	117.128520871	179.363770022	11.0041
31.813911031	117.128654341	180.463478212	14.0154

Table 2 Lateral control precision in straight lane

Average speed (km/h)	15	35	50	80
RMS of lateral control (m)	0.18	0.21	0.25	0.28

Table 3 Lateral control precision in curves

Types	Common curve (>90°)	Right-angled curve (=90°)	U-turn (<90°)
RMS of lateral control (m)	0.29	0.35	0.44

Table 4 Longitudinal control precision

Setting speed (m/s)	2.5	5.5	8	11	14	22
Real speed (minimum) (m/s)	1.84142	5.22533	7.77735	10.4112	13.2154	20.9821
Real speed (maximum) (m/s)	2.94660	5.98913	8.59982	11.1199	14.2838	22.8734
RMS of longitudinal control (m/s)	0.47823	0.45782	0.42327	0.35328	0.40319	0.49021

turning circumstances. In the process of curve test, the speed is set to idle speed (<20 km/h) to test the lateral control precision of various turning conditions.

Tables 2 and 3 show that the RMS of lateral control in straight lane is less than 0.3 m in all kinds of speeds and less than 0.5 m in curves with idle speed. The tests show that the automatic driving can meet the requirements of perception-planning layer on the lateral control precision and speed of the execution layer.

Our test of longitudinal control is implemented on a straight lane about 500 m. We obtained real speed-tracking data under the setting speed of 2.5, 5.5, 8, 11, 14, and 22 m/s in the same road type, respectively. When the vehicle travels stably, the upper computer sends the speed instructions, and then obtains the accuracy of longitudinal control by contrasting with the true vehicle speed. The RMS of longitudinal control is less than 0.5 m/s in different setting speeds, as shown in Table 4, it can meet the requirements of automatic driving.

After a series of road tests over 3,000 km within 4 months, the intelligent vehicle has proved itself as a robust platform which can travel on both structured and unstructured roads at a speed of 50 km/h. Under any circumstances, all four underlying subsystems operate flawlessly. The system perfectly meets all requirements of the underlying control system for intelligent vehicles.

6 Conclusion

An innovative universal automatic driving system for intelligent vehicle is designed in this research. The steering system with synchronous belt transmission is directly installed on the steering wheel, which uses electromagnetic clutch for two modes of switch, i.e., manual driving and automatic driving. The braking system, the throttle system, and the gear system use DC servo motors to drive ball screws and then pull the flexible shafts to control the braking, throttle and gearing states. The automatic driving system uses CAN bus to connect all four execution systems. The design method of the automatic driving system has advantages of good versatility, without complex mechanical design, making small changes to the original manned vehicle, which obtains the effects of high control precision, short development cycle, and low cost. It is proved by vehicle tests that the intelligent vehicle equipped with this system can drive within a specified path. The research experience can also provide useful reference for other construction of similar automated driving and remote control platforms.

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