The Modeling and Simulation of Vehicle Distance Control based on Cyber-physical System

Meng Qingxue
School of Information Science and Engineering
East China University of Science and Technology
Shanghai, China
mqx_2011@126.com

Lin Jiajun*
School of Information Science and Engineering
East China University of Science and Technology
Shanghai, China
jjlin@ecust.edu.cn

***Abstract*—With the advent of motorization, result in traffic system more congested, how to make the traffic system more effective and also take safety into account, namely build a intelligent transportation system, has become a hot spot of society. The vehicle distance control system studied in this paper is an important function in intelligent transportation system, through introducing cyber-physical systems (CPS) technology into it, set up system model, make the vehicles maintain a preset safety distance, thereby not only help improve the effective utilization of traffic system, but also help avoid the collision due to the speed change. Finally, use Simulink software to simulate and analyze the performance of the system, the result shows that the model can effectively cope with the distance change which is due to speed change, and ensure the vehicles maintain a preset safety distance within a short period of time.**

Keywords—CPS; intelligent transportation; vehicle distance control; safety distance

I. Introduction

Cyber-physical systems is a next generation of intelligent systems which combines physical environment, embedded computing, network communications and network control together, it has functions of computing, communication, autonomy, precise control, remote coordination. By contrast, the traditional embedded system is closed, not leave outside operation ports, can't meet the physical device controllable, reliable, extensible and other aspects of requirements[1]. About the definition of the CPS, different scholars gave their own opinions, Edward Lee defined the CPS as the integration of computing and physical process. S.Shanker Sastry thought a CPS system is integrating the computing and communication ability to physical entities, in order to meet the requirements of credible, safe, reliable, efficient and real-time control[2]. Nowadays, CPS has not only become the important direction of the academic and scientific research both at home and abroad, but also expected to enter into industrial field. It has significant meaning to carry out the research and application of the CPS in order to speed up promoting the industrialization and information fusion. In May 2005, the United States congress required the national academy of sciences evaluating their technical competitiveness and putting forward proposals to maintain and enhance the competitiveness, then the report of "Standing above the storm" based on this study published[3]. In July 2007, the United States President's Council of Advisors on Science and Technology (PCAST) listed the eight key information technologies in the report titled "Leading under the challenge-information technology research and development in the competitive world", the CPS ranked first[4]. The European Union planned to invest 5.4 billion Euros in advanced research and technology for embedded intelligence and system (ARTMEIS) from 2007 to 2013, expected to become the world leader in the intelligent electronic systems in 2016[5]. He Jifeng academician thought that, the next generation of industry will be based on the CPS, with the development and popularity of the CPS technology, physical devices using computer and network to realize the function of extension will be everywhere, and will promote the upgrading of industrial products and technology, greatly improve the competitiveness in main industrial areas such as automobile, aerospace, national defense, industrial automation, medical equipment and so on, the CPS will not only create a new industry, but also rearrange the existing industry layout. According to the United States national science foundation (NSF), CPS will let the whole world connected. As the Internet has changed the interpersonal interaction, CPS will change our interaction with the physical world. All in all, the ultimate goal of the CPS is to realize the total integration of information world and the physical world, building a controllable, reliable, scalable and secure network, and eventually change the way humans build physical system[6].

Another important concept is intelligent transportation system, it includes the vehicle control system, traffic monitoring and control system, vehicle management system, and travel information system. This paper mainly studies the vehicle distance control which is an important function in vehicle control system, it has significant meaning to effective and safe use of the road traffic. Firstly, in the rush hour of traffic, it will effectively improve the utilization rate of road by adjusting the distance to be the preset safety distance if the vehicle distance is large. In addition, the safety distance can also help avoid collision between vehicles once the front vehicle slow down or brake suddenly. In short, it is a set of automatic control system to adjust vehicle distance for the purpose of safety and efficiency, the system can greatly reduce the workload and labor intensity of the drivers. Its implementation is mainly through introducing the CPS technology into it, use the control system composed of on-board equipment and ground control center to complete the process control. This paper carried out modeling and

978-1-4799-4419-4 /14/$31.00 ©2014 IEEE

simulation analysis, the results show that it can achieve the desired effect.

II. SYSTEM STRUCTRUE

A. The Structure of Intelligent Transportation Systems

Nowadays, with the increment of vehicles on road, traffic pressure increasing, the congested traffic brings inconvenience to people's daily life, at the same time, also leads to a decline in productivity, and the waste of energy. So how to construct a intelligent transportation system which is efficient and safe has draw more and more attention from the society. An ideal intelligent transportation system needs to coordinate different manned and unmanned equipments, needs to set effectiveness, safety, stability and flexibility integrated, its system structure is shown in Fig. 1.

On the whole, the intelligent transportation system is mainly divided into three layers, the physical layer, network layer and application layer respectively[7]. The physical layer is mainly the intelligent agents embedded in a large number of sensing devices, computing devices, control devices, so the vehicles, roads, traffic lights are no longer simply mechanical equipments, they transmit information through the network layer, so as to realize interconnection with each other. In this way, a intelligent vehicle will not only get environment information from its own sensors, but also can get other information from other vehicles, roads and the traffic administrative department through the network layer, The network layer mainly includes the base station communications, satellite communications and many other kinds of communication modes, it can effectively shield the heterogeneity of the physical equipments, realize the seamless connection. Application layer mainly refers to the various user oriented software, such as the centralized monitoring software of traffic administrative department and onboard software of the intelligent vehicles, it can help realize the effective interaction between intelligent transportation system and people, so as to serve the people better.

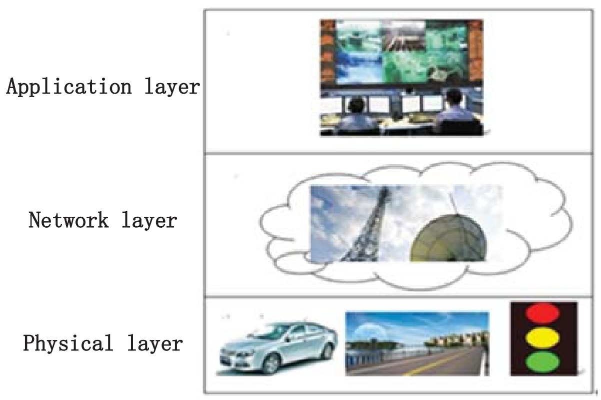

Fig. 1. Architecture of intelligent transportation system

B. The CPS Transaction Process

According to reference 8, can construct the CPS transaction process as shown in Fig. 2. It includes feedback loop, the physical device can perceive the real-time change of the physical environment through the sensors, then transmit the information to the computing unit. At the same time, the computing unit also completes the information exchange with the storage unit, communication unit and network respectively, finally realize information fusion, resulting in a correct recognition of the physical environment, then make a decision, control unit issues instructions to actuator unit to realize the influence on the physical environment.

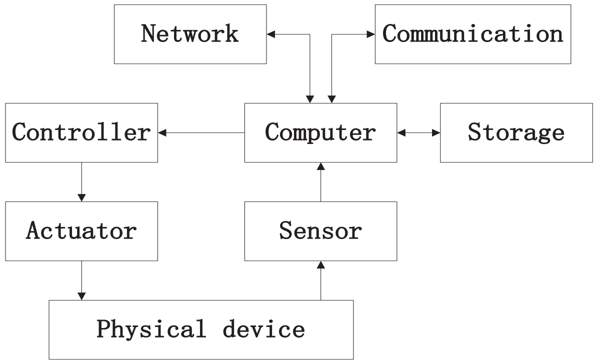

Fig. 2. The CPS transaction processes

C. The Structure of Vehicle Distance Control System Based on CPS

Suppose there are two vehicles A and B (vehicle A stands for the front one, vehicle B stands for the behind one) run in the same direction on the road, the initial distance is X, after a period of time, the displacement of vehicle B is X1, and displacement of vehicle A is X2, the distance between them changed to be L.

According to the CPS transaction process, as well as the specific driving condition of the two vehicles, can construct the basic structure of the distance control system based on CPS as shown in Fig. 3. Vehicle B as the controlled object of the whole system, the driving conditions (mainly for the change of speed) of vehicle A will affect the distance between them. once the distance measuring sensor embedded in vehicle B detects another vehicle into its lane, will immediately change to be the mode to maintain a safety distance, and transmit the measured information to the computing unit, then the computing unit complete information fusion also according to the other information from the storage unit and the network, make corresponding decision in order to maintain the safe distance. Namely, speed up when greater than the safety distance, speed down when less than the safety distance, they are realized by the traction and braking force respectively. Finally, the control circuit will issue instructions of traction or braking to control the accelerator and brake[9], so as to achieve the goal of maintaining the safety distance. All of the algorithms and the processes of the system implemented in its core computing unit, the computing unit put the information into the control algorithm, then release the control instructions through the output module[10].

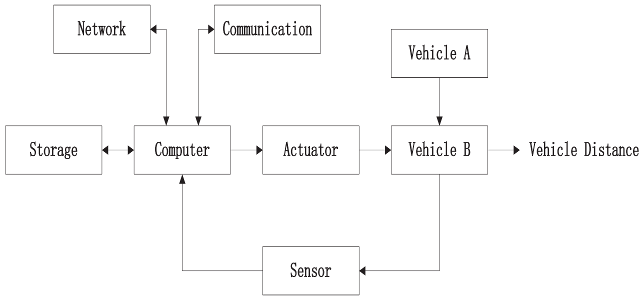

Fig. 3. Architecture of vehicle distance control system based on CPS

III. SYSTEM MODEL

This paper designed a kind of system model with simple structure and good stability, compared with previous distance control system, this system only need the distance measuring sensor detect whether there is vehicle enter the controlled vehicle's lane, then control the vehicles into the control mode. Once into this mode, according to the design of model can directly calculate the displacement of the two vehicles from their traction, then can get the real-time distance, finally, feedback the distance to computing unit for estimating, the specific modeling approach is as follows:

Set the displacement of controlled object as x, velocity as v, mass as m, traction of the engine as u, and suppose that the friction of hinder the movement is proportional to the velocity of the vehicle, then can build the following equation:

$$u - b\dot{x} = m\ddot{x} \tag{1}$$

Since what we are interested here is velocity, so the equation of motion can be rewritten as:

$$\dot{v} = -\frac{b}{m}v + \frac{1}{m}u \tag{2}$$

If the vehicle's displacement x and velocity v as state variables, namely $x = [x, v]^T$, then the equation describes the controlled object can be listed as below two first-order equations:

$$\begin{aligned} \dot{x} &= v \\ \dot{v} &= -\frac{b}{m}v + \frac{1}{m}u \end{aligned} \tag{3}$$

The above equations can be expressed as below vector equations in the form of a state variable:

$$\begin{aligned} \dot{x} &= Fx + Gu \\ y &= Hx + Ju \end{aligned} \tag{4}$$

In above equations x as the system state, if the order of the system is n, then it contains n elements. For mechanical system, the state vector of each element is usually the displacement and velocity of each individual. Parameter F is system matrix whose order is $n \times n$, parameter G is input matrix whose order is $n \times 1$, and parameter H is output matrix whose order is $1 \times n$, J is a scalar, called direct transmission term.

Equation (4) can be expressed in the standard form as below:

$$\begin{bmatrix} \dot{x} \\ \dot{v} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & -\frac{b}{m} \end{bmatrix} \begin{bmatrix} x \\ v \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{m} \end{bmatrix} u \qquad y = \begin{bmatrix} 1 & 0 \end{bmatrix} \begin{bmatrix} x \\ v \end{bmatrix} \tag{5}$$

The matrices in the form of state variables can be as follows:

$$F = \begin{bmatrix} 0 & 1 \\ 0 & -\frac{b}{m} \end{bmatrix}, G = \begin{bmatrix} 0 \\ \frac{1}{m} \end{bmatrix}, H = \begin{bmatrix} 1 & 0 \end{bmatrix}, J = 0 \tag{6}$$

Then can get the transfer function H(s) whose input is traction and output is displacement, and according to the moving process shown in Fig. 4 can get the distance between the two vehicles L is:

$$L = X2 - X1 + X \tag{7}$$

In order to reflect the velocity change of the vehicles more intuitively, can also calculate the corresponding transfer function, specific steps are as follows:

$$\begin{bmatrix} \dot{x} \\ \dot{v} \end{bmatrix} = \begin{bmatrix} 0 & 1 \\ 0 & -\frac{b}{m} \end{bmatrix} \begin{bmatrix} x \\ v \end{bmatrix} + \begin{bmatrix} 0 \\ \frac{1}{m} \end{bmatrix} u \qquad y = \begin{bmatrix} 0 & 1 \end{bmatrix} \begin{bmatrix} x \\ v \end{bmatrix} \tag{8}$$

The matrixes in the form of state variables are as below:

$$F = \begin{bmatrix} 0 & 1 \\ 0 & -\frac{b}{m} \end{bmatrix}, G = \begin{bmatrix} 0 \\ \frac{1}{m} \end{bmatrix}, H = \begin{bmatrix} 0 & 1 \end{bmatrix}, J = 0 \tag{9}$$

Thereby, in the same way, can get the transfer function H'(s) whose input is traction and output is velocity.

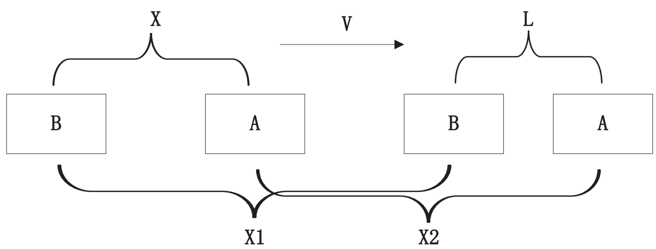

Fig. 4. Movement process of the two vehicles

IV. SYSTEM CONTROL PRINCIPLE

A. The Principle of System's Autonomous Function

The autonomous function of the system mainly rely on PID controller to realize, the computing unit of the system simply get the real-time distance information from the sensors. PID controller is a kind of approach use of proportion, integral and differential units to calculate the deviation of the measurements, then determine the output which is used for controlling the actuator. It is a linear controller, make the proportion (P), integral (I) and differential (D) of the deviation to be controlled variable through linear combination to control the controlled object, so that is why it is called PID controller, the algebraic equation of it is:

$$u(t) = K_p[e(t) + \frac{1}{T_i}\int_0^t e(t)dt + \frac{T_d de(t)}{dt}] \tag{10}$$

The transfer function of it is:

$$D_c(s) = K_p[1 + \frac{1}{T_i s} + T_d s] \tag{11}$$

B. The Principle of System's External Manipulation

From the perspective of the traffic administrative department, in order to realize the effective allocation of the transportation system under the specific road situation, it needs transmit corresponding information to the computing unit of the vehicle through the network layer, such as adjusting the preset safe distance, or a specific speed control. In other words, when the computing unit not only gets the real-time distance information from the sensors, but also obtains information from the network, communication and storage unit, it needs to build mathematical model for the computing unit. The modeling of computing unit is mainly about traction and braking force. Namely, speed up when the distance larger than the preset distance, which is mainly rely on traction. Speed down when less than the safety distance, which is mainly rely on braking force. Traction value generally come from automobile traction characteristics data, according to the gear of handle (different gear corresponding different traction characteristic curve) and the current speed, can get the current vehicle traction value[7]. For example, suppose that the given two points $A(v_1, F_1)$ and $B(v_2, F_2)$ are the points of a certain automobile traction characteristic curve, $X(v_x, F_x)$ is a unknown point between point A and point B. v_x is the determined velocity for making the distance of the vehicles approach the preset safety distance after the computing unit obtain the information from sensors, network, communication and storage units. F_x is the specific traction value for realizing the velocity v_x , so make use of the method of linear interpolation, can get the traction value of this point as follows:

$$F_x = \frac{(v_x - v_1)(F_2 - F_1)}{v_2 - v_1} \tag{12}$$

The calculation method of braking force is similar to the traction, it is refer to the vehicle's braking characteristic curve, according to the expected velocity calculating from the computing unit, using linear interpolation method [11]or curve fitting method[12], can get the corresponding braking force value. The realization of this function need the computing unit meet the requirements of having large numbers of storage data and the ability of accurately calculating simultaneously. The comprehensive and detailed work will need to be further discussed.

V. SIMULINK SIMULATION AND ANALYSIS

Through the simulation of system to manifest the performance of it, suppose the initial distance of the two vehicles is 25m, and both of their initial velocity is zero, in order to reflect the system's anti-interference performance, the front vehicle's velocity change as show in Fig. 5, the overall trend is speed up firstly, and then speed down.

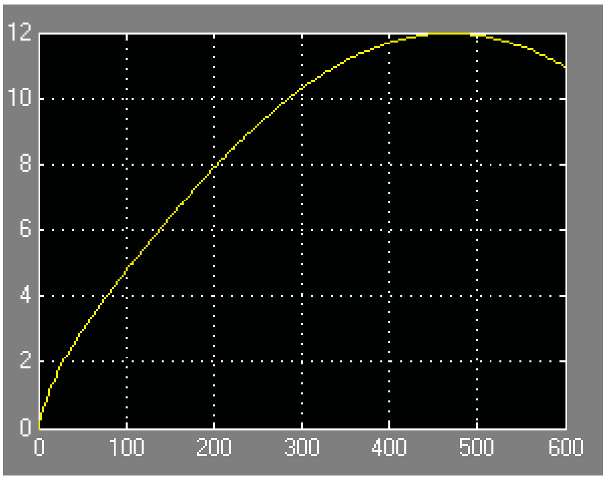

Fig. 5. Velocity change curve of front vehicle

The simulation result shown in Fig. 6, it shows that the distance between the two vehicles shortens to 14 meters quickly from the initial 25 meters, and become stable at the preset safety distance 15 meters after 100 seconds. Overall, the response of the system is faster, the fluctuation of the distance is smaller, and the control accuracy is relatively high.

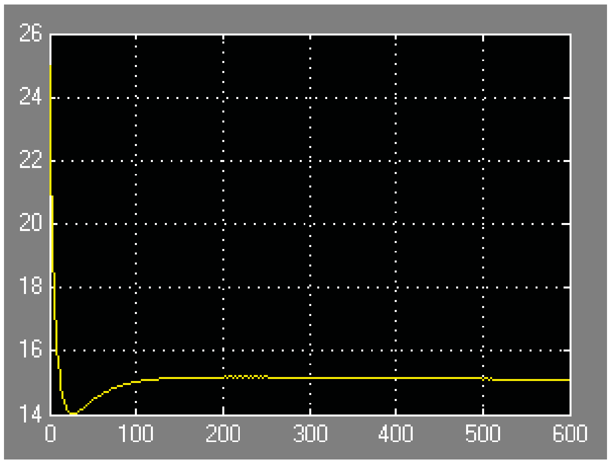

Fig. 6. Distance change curve of the vehicles

The error simulation result shown in Fig. 7, it manifests the system is stable.

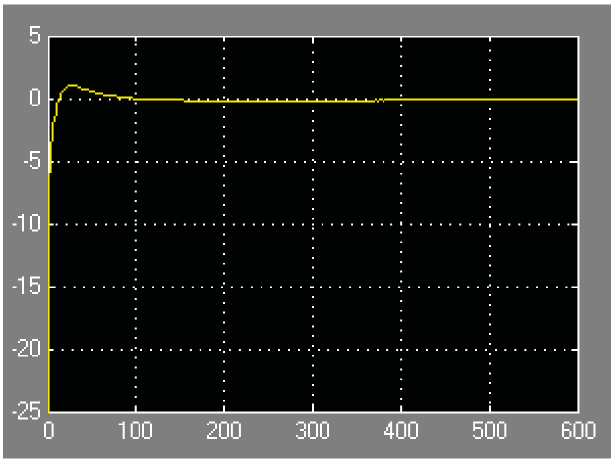

Fig. 7. Error analysis

In addition, from the velocity change curve of behind vehicle shown in Fig. 8 can see clearly that the velocity of the controlled vehicle basically changed with the front one.

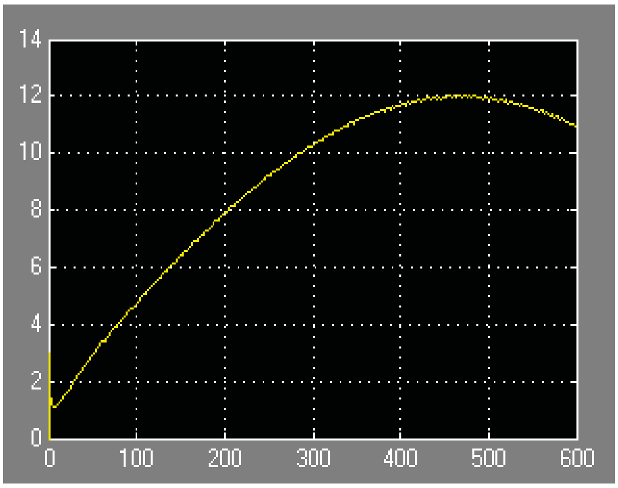

Fig. 8. Velocity change curve of behind vehicle

VI. CONCLUSION

In order to realize the effective use of road traffic, and reduce the accident of collision, propose that introduce the CPS technology into transportation system, build the vehicle distance control system based on CPS. This paper firstly introduces the related concepts of the CPS and intelligent transportation systems, and then put forward corresponding opinions on autonomous function and remote control function respectively. About the realization of the function of autonomy, in this paper, the mathematical model is established, and use simulates under the condition that front vehicle speed up first and then speed down, the results show that the system can effectively guarantee the safety distance between the two vehicles, get a relatively satisfactory control effect. As to the function of remote control, this paper proposes using linear interpolation method or curve fitting method, and its comprehensive and detailed work need to be discussed in the future research.

REFERENCES

[1] Liu Xiangzhi, Liu Xiaojian, Wang Zhixue, Cheng Wei, Li Jianxin. A Cyber-Physical System [J]. ShanDong Science, 2010, 23(3): 56-61.

[2] Lee E A. Cyber-physical systems-are computing foundations adequate[C]//Position Paper for NSF Workshop On Cyber-Physical Systems: Research Motivation, Techniques and Roadmap. 2006, 2.

[3] Augustine N R. Rising above the gathering storm: Energizing and employing America for a brighter economic future [J]. Retrieved March, 2005, 19: 2008.

[4] Marburger J H, Kvamme E F, Scalise G, et al. Leadership under challenge: Information technology R&D in a competitive world. An assessment of the federal networking and information technology R&D program[R]. EXECUTIVE OFFICE OF THE PRESIDENT WASHINGTON DC PRESIDENT'S COUNCIL OF ADVISORS ON SCIENCE AND TECHNOLOGY, 2007.

[5] Tsarchopoulos P. European research in embedded systems [M]//Embedded Computer Systems: Architectures, Modeling, and Simulation. Springer Berlin Heidelberg, 2006: 2-4.

[6] He Jifeng. Cyber-physical System [J]. China Computer Federation, 2010, 6(1): 25-29.

[7] Chen Lina, Wang Xiaole, Deng Su. Cyber-physical System Architecture Design [J]. Computer Science, 2011, 38(5): 295-300.

[8] Wang Xiaole, Chen Lina, Huang Hongbin, Deng Su. A Service-Oriented Architecture Framework of Cyber-Physical System [J]. Journal of Computer Research and Development, 2010, 47(S2): 299-303.

[9] Ding Weidong, Liu Zupeng, Zhu Xiaohong. A Study of Longitudinal Vehicle-to-vehicle Distance Control [J]. China Mechanical Engineering, 2004, 15(11): 1030-1032.

[10] Li Zijun. Research of Automatic Train Operation System Based on Fuzzy Self-Adaptive PID [D]. Beijing Jiaotong University, 2010.

[11] Yi Dayi, Chen Daoqi. Numerical Analysis. Zhejiang University Press, 1998.

[12] Hao Huijuan, Zhan Yulin, Song Huiying, Wei Qiang. Determination of Proximity Effect Parameters Based on Nonlinear Curve Fitting [J]. Microfabrication Technology, 2006 (2): 12-15.