Research on Consistency Problem of Network Multi-agent Car System with State Predictor

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Abstract

As the basis of the cooperative control of multi-agents, consistency theory attracts much attention from many different fields. However, the previous control law is often suboptimal; it only makes use of the local information of intelligent individuals. At the same time, the processor can only handle the information of the sampling time, intelligent car and its neighbor car only intermittent communication, which cannot guarantee the continuous transmission of information. In this paper, the state predictor is introduced. And the consistency theory with state predictor is applied to the study of the speed consistency problem of the multi-intelligent car system based on wireless network. The speed consistency algorithm of the wireless communication network intelligent car is given, and the influence of various coupling modes on the speed consistency of intelligent trolley is analyzed. Compared with the previous consistency algorithm [1], the reference of the intelligent car state predictor accelerates the convergence speed of the intelligent car to the equilibrium state. Finally, the control law of the state predictor is solved by the Euler formula, and the controller and the overall design scheme of the intelligent car are designed, and the feasibility of the controller is proved theoretically.

Keywords

Consistency theory; Multi-agent car; Convergence speed; State predictor; Coupled communication.

1. Introduction

The multi-agent consistency problem means that one or more physical quantities of all the individuals in the system tend to be consistent. The consistency algorithm gives the rules for the exchange of information between each agent and its neighbors. It points out that the speed of multi-agent system's consistency is related to the communication topology of multi-agent. Reza gives the consistency algorithm of a typical first-order multi-agent system which indicates that the speed of convergence of the system to the equilibrium state is related to its algebraic connectivity. Yoonsoo proposed a method based on semi-definite programming to change the communication topology of multi-agent system to speed up the evolution of the system to equilibrium state. However, this method requires one-to-one direct communication between intelligent individuals and other agents, and requires intelligent individuals have a strong computing power [2], which is difficult in practical application. Therefore, the above control algorithm is often suboptimal.

In this paper, a state predictor is introduced in which each agent can predict the future of its neighbor agent by finite communication, which increases the minimum nonzero eigenvalue of the multi-agent system and accelerates the speed of the multi-agent system's consistency. The consistency theory with state predictor is applied to the study of the speed consistency problem of the multi-intelligent car system based on wireless network, which simulation results show that the introduction of the state predictor can accelerate the evolution of the intelligent car to the equilibrium state, and solve the above control law through the Euler formula. The controller of the intelligent car system is designed, and the feasibility of the controller is proved theoretically.

2. The analysis of the consistency problem

The speed consistency of intelligent car refers to the speed of each car eventually converge. Graph theory, as an important tool for consistency analysis, can represent the rules of information exchange among multiple agents. The Palladian matrices and their spectral characteristics in graph theory are the key to the analysis of system consistency. The system consists of n cars, the speed of each car were v1, v2, ... , vn. Its set V $=\{v_1, v_2, \ldots, v_n\}$, edge set E$\subseteq$V$\times$V, weighted adjacency matrix A=[a_{ij}] all its elements are nonnegative real numbers. If (v_i, v_j) is an edge, that is $(v_i, v_j)=e_{ij}\in$E, then a> 0, and the device i can accept the information of device j. There is local communication between the i-th car and the j-th car. Its network topology G = (V, E, A) [3], where each agent speed, is the local control protocol. If the final speed of the car tends to be consistent, $\| x_i - x_j \| \to 0, \forall i \neq j$, information can only be obtained from the field, .

3. Consistency algorithm of intelligent car in wireless network

3.1 Consistency algorithm under ideal condition

For the system composed of n intelligent cars, is the speed information of the i-th intelligent car, the speed is the state quantity that the intelligent car needs to achieve consistency, we set the multi-intelligent car system as the continuous time linear system, which algorithm control law can be written as follows.

$\dot{x}_i = \sum_{j=1}^{n} b_{ij}[x_j - x_i]$. Describe the whole system as a matrix $\dot{X} = BX$, $X = [x_1, x_2, \ldots, x_n]^T$, $B = [b_{ij}] = -L$

When $b_{ij} = b_{ji}$, it is easy to prove that can converge;

When $b_{ij} \neq b_{ji}$, we need to ensure that $\sum_{j=1}^{n} b_{ij} = 0$, so that it can also prove that can reach convergence.

3.2 Consistency algorithm with time delay

Intelligent car a communication delay is fixed as τ, then the system consistency algorithm control law can be written in the following form.

$\dot{x}_i = \sum_{j=1}^{n} b_{ij}[x_j(t-\tau) - x_i(t-\tau)]$. Describe the whole system as a matrix $\dot{X} = BX(t-\tau)$.

3.3 Convergence speed of consistency algorithm

For undirected graphs and connected, Laplacian L is positive semidefinite. And all eigenvalues are nonnegative real numbers [4]. 0 is a singular eigenvalue of Laplace L with a corresponding eigenvector of 1. Its minimum non-zero eigenvalue is called the algebraic connectivity of L. $\lambda_2 = \min_{\substack{x\neq 0 \\ 1^T x=0}} \frac{x^T L x}{\| x \|^2}$.

The convergence rate of the consistency algorithm is related to the minimum nonzero eigenvalue λ_2 of Laplacian L of the network topology graph. The larger λ_2 is, the faster the multi-agent converges to the equilibrium state.

For the communication delay τ existing in actual intelligent car system, when the time delay satisfies $\tau < \tau_{\max} = \pi / 2\lambda_n$, the multi-agent system can still reach the same degree. The bigger the algebraic connectivity λ_2 of L, the bigger the λn, the faster the system converges to the same speed and at the same time $\pi/2\lambda_n$ is smaller. So there is a compromise between the speed of convergence and the robustness of anti-delay.

4. Consistency algorithm of intelligent car in wireless network with state predictor

The control law of the prior consistency algorithm only utilizes the local information around the individual. And the system wants to get global information to achieve optimal, multi-agent system through the communication network to obtain global information. But the overall size of the system is unknown, can not determine whether the information obtained for the global information. Therefore, it is not feasible in practice to design the control law by means of communication to obtain the global information of the system.

In order to solve the contradiction between the suboptimality of local information and the infeasibility of obtaining global information, a state predictor is designed. By means of finite communication, each agent can predict the future of its neighbor agent and use this predicted state to construct the control law, accelerates the convergence speed of system to the equilibrium state.

The state predictor is introduced to predict the change trend of the speed of the intelligent trolley system. in each intelligent car after the calculation by wireless communication is delivered to its neighbor car, the as a change in the state of the car into the control law of the design, speed up the intelligent car convergence to a consistent state of speed. The following control laws are designed in this way. The whole system is described by matrix:

$$\begin{cases}\dot{X}=CX\\ C=-(L+\gamma L^2)\end{cases}$$

$\gamma>0$ is the influence factor of the intelligent trolley state predictor.

If the communication topology is undirected, $X^TLX=\frac{1}{2}\sum_{(i,j)\in E}a_{ij}(x_j-x_i)^2$. Taking $G(X)=\frac{1}{2}X^T(L+\gamma L^2)X$, the undirected graph L is a semi-definite matrix, $\gamma>0$,and $G(X)\ge 0,G(\dot{X})\le 0$. Since L has only one zero eigenvalue, $L+\gamma L^2$ has only one zero eigenvalue. Let X^* be the equilibrium point of system $\dot{X}=-(L+\gamma L^2)X$, then $-(L+\gamma L^2)X^*=0$. It indicate that X^* is the right eigenvector corresponding to zero eigenvalue of $L+\gamma L^2$, so X^* can make $X^{*T}(L+\gamma L^2)X^*=0$. Since L and γL^2 are semi-definite, $X^{*T}LX^*=0$ $X^{*T}\gamma L^2X^*=0$, $X^{*T}LX^*=\frac{1}{2}\sum_{(i,j)\in E}(x_i^*-x_j^*)^2=0$, and $\forall i,j,x_i^*=x_j^*=a$, a is the equilibrium state. In summary, the multi-agent system state is shown in Equation (1).

$$X\to\left\{X^*\mid X^*=(x_1^*,x_2^*,\dots,x_n^*)^T=\overbrace{(a,a,,a)^T}^{n}\right\}\tag{1}$$

It is proved that if the communication topology is connected, the above-mentioned state predictor can make the system asymptotically consistent and faster than the system without the state predictor. Since the communication topology is connected and the Laplacian matrix is semi-definite, there exists a nonsingular matrix P such that the Laplacian matrix can be expressed in the form of the following Equation (2) and (3).

$$L = P^{-1}\begin{bmatrix} \lambda_n & & & \\ & \ddots & & \\ & & \lambda_2 & \\ & & & 0 \end{bmatrix} P, 0 < \lambda_2 \le \cdots \le \lambda_n = \lambda_{\max} \tag{2}$$

$$L + \gamma L^2 = P^{-1}\begin{bmatrix} \lambda_n + \gamma\lambda_n^2 & & & \\ & \ddots & & \\ & & \lambda_2 + \gamma\lambda_2^2 & \\ & & & 0 \end{bmatrix} P, \tag{3}$$

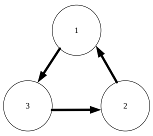
Observing the above two formulas, for any γ>0, $\lambda_2 + \lambda_2^2 > \lambda_2$, systems with state predictors have a larger minimum nonzero eigenvalue, which is faster than a stateless predictor system.

5. Simulation of consistency algorithm

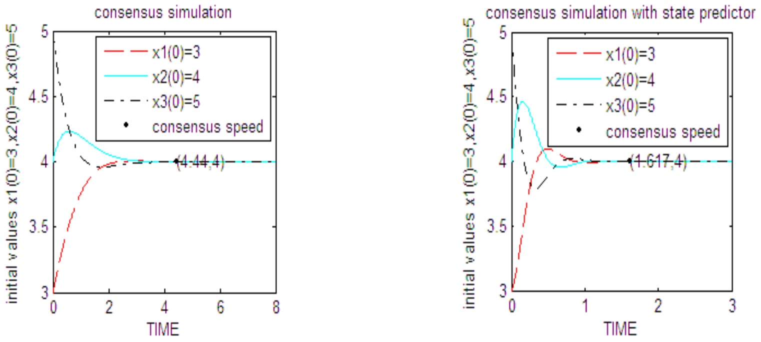
Suppose there are three smart cars, the corresponding initial speed were $x_1(0) = 3, x_2(0) = 4, x_3(0) = 5$, state predictor γ value of 2, we have given four different communication topology, the composition of the coupling Matrix and the corresponding simulation results as shown.

$$\mathrm{B} = \begin{bmatrix} -1, & 1, & 0 \\ 0, & -1, & 1 \\ 1, & 0, & -1 \end{bmatrix} C_{1=} \begin{bmatrix} -3, & 5, & -2 \\ -2, & -3, & 5 \\ 5, & -2, & -2 \end{bmatrix}$$

(a) Coupled matrix 1



(b) Communication topology

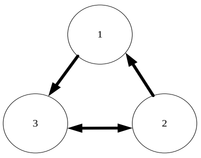


(c) Consensus simulation 1 (d) Consensus simulation 1 with state predictor

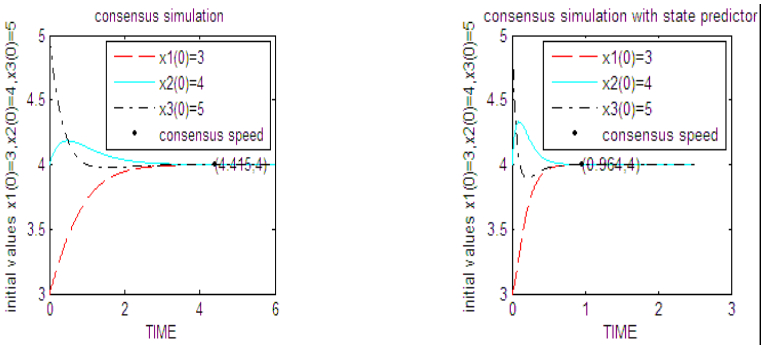
Fig. 1 Coupled matrix 1&Simulation figure1

$$B_2 = \begin{bmatrix} -1, & 1, & 0 \\ 0, & -1, & 1 \\ 1, & 1, & -2 \end{bmatrix} C_{2=} \begin{bmatrix} -3, & 5, & -2 \\ -2, & -5, & 7 \\ 7, & 5, & -12 \end{bmatrix}$$

(a) Coupled matrix 2



(b) Communication topology 2

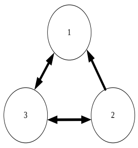


(c) Consensus simulation2 (d) Consensus simulation 2 with state predictor

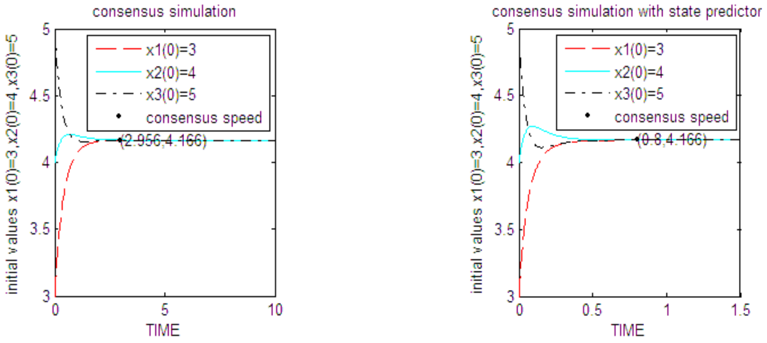
Fig. 2 Coupled matrix 2&Simulation figure2

$$B_3 = \begin{bmatrix} -2, & 1, & 1 \\ 0, & -1, & 1 \\ 1, & 1, & -2 \end{bmatrix} \quad C_{3=} \begin{bmatrix} -3, & 5, & -2 \\ -2, & -3, & 5 \\ 5, & -2, & -2 \end{bmatrix}$$

(a) Coupled matrix 3



(b) Communication topology 3

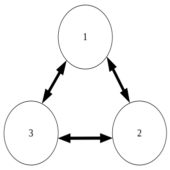


(c) Consensus simulation 3 (d) Consensus simulation 3with state predictor

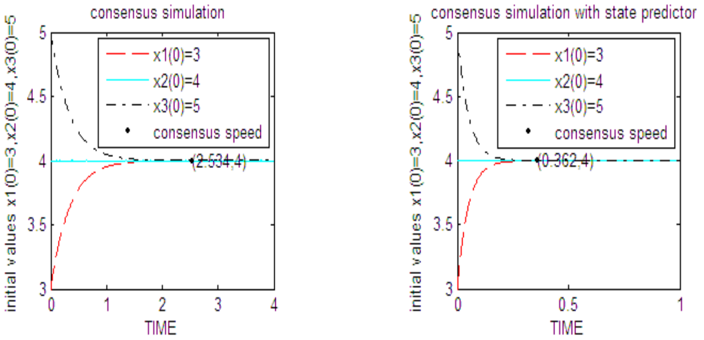
Fig. 3 Coupled matrix 3&Simulation figure3

$$B_4 = \begin{bmatrix} -2, & 1, & 1 \\ 1, & -2, & 1 \\ 1, & 1, & -2 \end{bmatrix} \quad C_{4=} \begin{bmatrix} -12, & 5, & -2 \\ -2, & -5, & 7 \\ 9, & 5, & -14 \end{bmatrix}$$

(a) Coupled matrix 4



(b) Communication topology 4



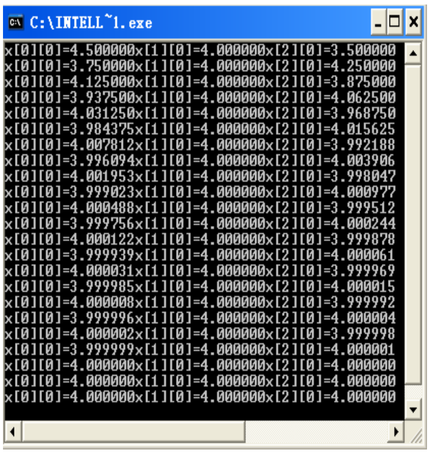
(c) Consensus simulation 4 (d) Consensus simulation 4 with state predictor

Fig. 4 Coupled matrix 4&Simulation figure4

The Simulation results we analyze is presented in Fig.1 , Fig.2, Fig.3, Fig.4. When matrix B satisfy the following properties: *i*) $b_{ii} < 0$; *ii*) $b_{ij} \geq 0, i \neq j$, the multi-agent car can reach consensus speed. Strengthening the communication between the intelligent car and the introduction of the state predictor can accelerate convergence rate to reach consensus speed. The introduction of the state predictor does not affect the consensus state of smart car[5]. Due to the asymmetric communication topology structure of the car, the ultimate speed of each car is not necessarily average-consensus of initial values.

6. Design of intelligent car system controller with state predictor

We apply the consistency control law of the state predictor with the state topology of communication 4 to the system composed of three intelligent trolleys. Before implementing the hardware platform design, we use the software to realize the controller of the system. We solve the control law through the Euler formula, draw an iterative formula and continue to draw the speed of the next car. We use the microcontroller to achieve this iterative process. The following Fig. 5 is a computer theory to verify the control law and run the results.



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x[0][0]=4.500000x[1][0]=4.000000x[2][0]=3.500000
x[0][0]=3.750000x[1][0]=4.000000x[2][0]=4.250000
x[0][0]=4.125000x[1][0]=4.000000x[2][0]=3.875000
x[0][0]=3.937500x[1][0]=4.000000x[2][0]=4.062500
x[0][0]=4.031250x[1][0]=4.000000x[2][0]=3.968750
x[0][0]=3.984375x[1][0]=4.000000x[2][0]=4.015625
x[0][0]=4.007812x[1][0]=4.000000x[2][0]=3.992188
x[0][0]=3.996094x[1][0]=4.000000x[2][0]=4.003906
x[0][0]=4.001953x[1][0]=4.000000x[2][0]=3.998047
x[0][0]=3.999023x[1][0]=4.000000x[2][0]=4.000977
x[0][0]=4.000488x[1][0]=4.000000x[2][0]=3.999512
x[0][0]=3.999756x[1][0]=4.000000x[2][0]=4.000244
x[0][0]=4.000122x[1][0]=4.000000x[2][0]=3.999878
x[0][0]=3.999939x[1][0]=4.000000x[2][0]=4.000061
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x[0][0]=3.999985x[1][0]=4.000000x[2][0]=4.000015
x[0][0]=4.000008x[1][0]=4.000000x[2][0]=3.999992
x[0][0]=3.999996x[1][0]=4.000000x[2][0]=4.000004
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x[0][0]=3.999999x[1][0]=4.000000x[2][0]=4.000001
x[0][0]=4.000000x[1][0]=4.000000x[2][0]=4.000000
x[0][0]=4.000000x[1][0]=4.000000x[2][0]=4.000000
x[0][0]=4.000000x[1][0]=4.000000x[2][0]=4.000000
```

Fig. 5 Controller theoretical calculation results

In the case of the initial velocity $x_1(0) = 3, x_2(0) = 4, x_3(0) = 5$, the calculation results are approached to one-third of the sum of the initial velocity and eventually converge to the velocity 4. The system state is consistent, which verifies that the controller is theoretically feasible.

7. Overall design scheme of wireless network intelligent car system

In the multi-agent car system, the intelligent car is used as a single node. The whole system consists of three identical smart car. According to the car's photoelectric encoder[6], the speed information of the small car can be obtained. The intelligent car can realize the wireless information of speed information through the XBee ZigBee module. Through the process of consistency analysis

Sending control commands to the car actuator - DC motor drive through the process of consistency analysis, intelligent car can make their own speed on their own decision-making and control. Ultimately, the speed consistency control of the multi-intelligent car is realized. System block diagram as shown below[7].

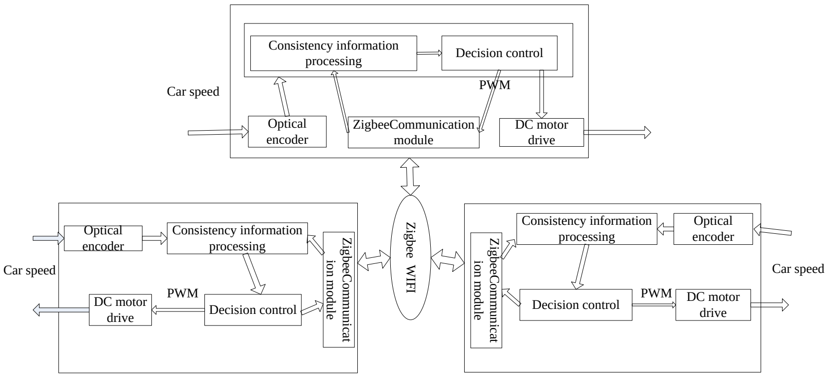

Fig. 6 Block diagram of wireless network multi intelligent car system

8. Conclusion

This paper first introduces the important tools for analyzing the consistency problem: graph theory and matrices. The graph theory is applied to the speed consistency control of the multi-intelligent car system. The vertices in graph theory represent the intelligent carts, and the directional links between the points represent the coupling communication between the intelligent small shops. The speed consistency algorithm of the intelligent car under the ideal state and delay state is given to analyze the convergence speed of the consistency algorithm. By introducing the state predictor, the convergence rate of the consistency algorithm is accelerated, and the validity of the car consistency algorithm is verified by Matlab simulation. The consistency control law of the intelligent car system with the state predictor mentioned above is solved by the Euler formula, and the system controller is realized by software. Then, the controller theory is proved to be feasible by computer theory. At last, the overall design scheme of intelligent car is given, and the speed consistency control of the multi-intelligent trolley is realized.

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