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# Design of Autonomous Cruise Controller with Linear Time Varying Model

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**Abstract** – Cruise control is a technology for automatically maintaining a steady speed of vehicle as set by the driver via controlling throttle valve and brake of vehicle. In this paper we investigate cruise controller design method with consideration for distance to vehicle ahead. We employ linear time varying (LTV) model to describe longitudinal vehicle dynamic motion. With this LTV system we approximately model the nonlinear dynamics of vehicle speed by frequent update of the system parameters. In addition we reformulate the LTV system by transforming distance to leading vehicle into variation of system parameters of the model. Note that in conventional control problem formulation this distance is considered as disturbance which should be rejected. Consequently a controller can be designed by pole placement at each instance of parameter update, based on the linear model with the present system parameters. The validity of this design method is examined by simulation study.

**Keywords**: Autonomous cruise control, Adaptive cruise control, Linear parameter varying system, Linear time varying system

## 1. Introduction

Cruise control system automatically regulates the longitudinal speed of an automotive vehicle. The system adjusts the vehicle throttle in order to maintain a steady velocity which is set by the driver. Thus this system can relieve driver's physical fatigue particularly when driving long distance. In addition it is helpful to improve the fuel efficiency by maintaining a constant longitudinal speed of the vehicle.

Autonomous cruise control (ACC), also referred as adaptive cruise control or intelligent cruise control, is a general term meaning advanced cruise control, which is recently offered as an option for prestige automobile. If a leading vehicle is present in a certain distance range, then ACC system adjusts the vehicle speed in headway-control mode so as to secure a safe headway. Otherwise ACC system is equivalent to conventional cruise control, keeping a target vehicle speed.

A number of researches on cruise control have been published in the last decades: the authors of [1] have summarized some achievement of automatic vehicle control and the program on advanced technology for the highway.

A broad review on advanced vehicle control system has been provided in [2]. To reduce driver's mistake an autonomous cruise control system has been developed in [3]. An advanced cruise control system has been studied to consider traffic flow density and interval policy in [4]. Based on flow stability and gap-policy optimal control controller has been designed in [5]. ACC to control gap of vehicles and traffic flow has been investigated with the help of communication between vehicles in [6]. In [7] it has been shown that adaptive cruise control has advantages for safety problem of collision avoidance system.

ACC problem has been studied via various control theories and just few of them are listed in what follows: an ACC controller based on fuzzy logic has been researched to keep a safe distance to the vehicle ahead [8, 9]. The stability problem of traffic flow has been addressed in [10] when ACC system with constant time-gap policy between vehicles is operated. In the meanwhile a nonlinear range policy for ACC vehicles has been presented in [11] to improve traffic flow stability. Model predictive control technique has been applied to calculate the control law of ACC system in [12, 13]. As an extended ACC, cooperative

ACC with wireless communication has been examined for the effect on traffic flow in [14]. A model based ACC has been suggested in [15] based on a nonlinear reference model with which constraints for safety and comport specifications can be defined. Recently a virtual lead vehicle scheme has been introduced to calculate the distance with simplified structure of the control system so that can control the motion of the vehicle smoothly when a new leading vehicle cuts in or out [16]. Also the integration of a curve speed control algorithm with ACC system has been

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researched based on experimental data of driver behaviour [17].

Among these many research results we employ a dynamics model of [18], exploited to develop our control method and we examine this control scheme based on the same model. By doing this the performance of our controller can be directly compared to that of the controller in [18] and it shows the performance improvement by our control idea.

In this paper we consider the controller design problem for the headway-control mode of ACC system. The purpose of this paper is to develop a design method for cruise controller to regulate distance between the controlled vehicle and lead vehicle. To this end we develop linear time varying (LTV) model to describe longitudinal vehicle dynamic motion. With this LTV system we can model the nonlinear dynamics of vehicle speed approximately by periodical renewal of the system parameters. Furthermore we reformulate the LTV system by transforming distance to leading vehicle into variation of system parameters of the model. In conventional control problem formulation this distance has been generally considered as disturbance input which should be rejected. In this paper we design a new controller using pole placement at each instance of parameter update, based on the linear model with the updated system parameters. Note that we only focus on controller design based on pole placement technique for given desired poles but the determination of the desired poles is not in the scope of this paper. The feasibility of this design method is studied with numerical simulation.

The paper is organised as follows. We revisit the work of [18] to introduce a dynamic model for design of adaptive cruise controller in Section 2. Then we examine the performance of the headway controller considering various changes of the leading vehicle velocity and time varying system parameters in Section 3. It suggests a new controller design method based on linear time varying system approach as well as simulation study of the application of the proposed control scheme in Section 4. Finally the paper is concluded by providing additional remarks on the results and future research directions in Section 5.

## 2. Model for Speed and Headway Control

The dynamic vehicle model considered in this research is derived in [18]. In this section we provide a brief introduction of the model and the parameters as well as a summary of the research result with the model. Thus a problem formulation for ACC controller design is suggested in this section. All the notations and coordinates of this paper follow the description standard of SAE for vehicle dynamics [19]. By linearisation of the longitudinal dynamics of the controlled vehicle and the lead vehicle 3-dimensional state equations are obtained in [18], namely

$$\begin{aligned} \dot{x}_1 &= x_3 - x_2, \\ \dot{x}_2 &= -\frac{1}{\tau_c}x_2 + \frac{K_c}{\tau_c}u + \frac{K_c}{\tau_c}w_c, \\ \dot{x}_3 &= -\frac{1}{\tau_l}x_3 + -\frac{K_l}{\tau_l}w_l, \end{aligned} \tag{1}$$

where $x_1 = d$, the distance between these two vehicles, $x_2 = v_c$, the longitudinal velocity of controlled vehicle, $x_3 = v_l$, the longitudinal velocity of lead vehicle, and u is the control input applied to the controlled vehicle. $w_c$ and $w_l$ are disturbances for the controlled vehicle and the lead vehicle, respectively. $K_c$ and $\tau_c$ are the plant-model parameters for the controlled vehicle, while. $K_l$ and $\tau_l$ for the lead vehicle.

Now we assume that $d$ and $v_c$ are measurable and introduce a reference $r$ as the desired headway. Then, in order to determine the control input $u$, we design a feedback controller based on the following model of [18], namely

$$\begin{aligned} \dot{x}_1 &= -x_2 + v_l, \\ \dot{x}_2 &= -\frac{1}{\tau_c}x_2 + \frac{K_c}{\tau_c}u + \frac{K_c}{\tau_c}w_c, \\ \dot{x}_3 &= x_1 - r, \\ \dot{x}_4 &= x_3 \end{aligned} \tag{2}$$

Where $x_1$=d, $x_2$=$v_c$, and $u = -k_1x_1 - k_2x_2 - k_3x_3 - k_4x_4$. Note that $x_3$ is the integral of the error $d - r$, while $x_4$ the double integral.

Let $x := [x_1, x_2, x_3, x_4]^T$ and $z := [r, w_c, v_l]^T$. Now we rewrite the system (2) in the following state space form

$$\dot{x} = A_a x + B_a u + B_c z, \tag{3}$$

where

$$A_a = \begin{bmatrix} 0 & -1 & 0 & 0 \\ 0 & -1/\tau_c & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}, \quad B_a = \begin{bmatrix} 0 \\ K_c/\tau_c \\ 0 \\ 0 \end{bmatrix},$$

and

$$B_c = \begin{bmatrix} 0 & 0 & 1 \\ 0 & K_c/\tau_c & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}. \tag{4}$$

To calculate the controller gains (i.e. $k_1, k_2, k_3,$ and $k_4$) a design model by pole placement has been employed in [18]. This design procedure can be realised with the help of computational tool, such as Matlab, considering $z$ as disturbance to the system (3). Four poles, $s_1, s_2, s_3,$ and $s_4$, of the closed loop system have been suggested as $s_1 = -\xi\omega_n + j\omega_n\sqrt{1-\xi^2}$, $s_2 = -\xi\omega_n - j\omega_n\sqrt{1-\xi^2}$, $s_3 = -\alpha\xi\omega_n$, $s_4 = s_3 - m$ where $\xi = 0.9, \omega_n 0.4, \alpha 3,$ and m=01.

In order to evaluate the performance of the designed controller by simulation, five dimensional system has been proposed in [18], namely

$$\begin{aligned}
\dot{x}_1 &= -x_5 + x_2, \\
\dot{x}_2 &= -\frac{1}{\tau_c}x_2 + \frac{K_c}{\tau_c}u + \frac{K_c}{\tau_c}w_c, \\
\dot{x}_3 &= x_1 - r, \\
\dot{x}_4 &= x_3, \\
\dot{x}_5 &= -\frac{1}{\tau_l}x_5 + \frac{K_l}{\tau_l}w_l,
\end{aligned} \tag{5}$$

where the lead vehicle speed $v_l$ is considered as the state $x_5$.

Let $x_0 := [x_1, x_2, x_3, x_4, x_5]^T$ and $z_0 := [r, w_c, w_l]^T$. Then we can rewrite the system (5) in the following state space form

$$\dot{x}_0 = A_0 x_0 + B_0 z_0, \tag{6}$$

where

$$A_0 = \begin{bmatrix} 0 & -1 & 0 & 0 & 1 \\ -k_1K_c/\tau_c & -(1+k_2K_c)/\tau_c & -k_3K_c/\tau_c & -k_4K_c/\tau_c & 0 \\ 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & -1/\tau_l \end{bmatrix}$$

and

$$B_c = \begin{bmatrix} 0 & 0 & 0 \\ 0 & K_c/\tau_c & 0 \\ -1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & K_l/\tau_l \end{bmatrix}$$

The simulation result with the system (6) is illustrated in Fig. 1. The parameters used in this simulation are given as $K_c = 0.037$, $\tau_c = 36.9754$, $K_l = 0.0237$, $\tau_l = 35.5533$, $w_c = 0$, and $r = 30(m)$.

By appropriate manipulation of $w_l$, a modest decelerating maneuver of the leading vehicle is implemented in this simulation (see the middle graph in Fig. 1). Note that the distance range is kept relatively close to the set level $r$ =30(m) although the velocity of the lead vehicle varies considerably.

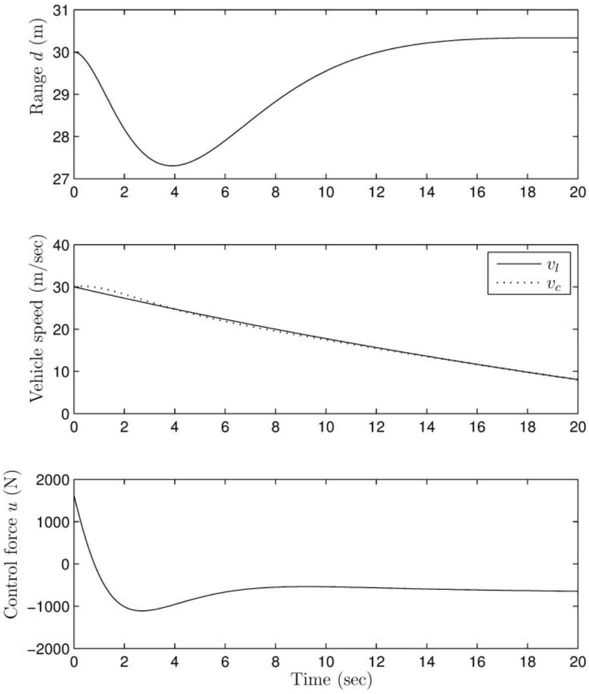


**Fig. 1.** Simulation result for a control problem in [18] using the model (6) with the given parameters in Section2.

## 3. Evaluation of the Headway Controller

In this section we first investigate the performance of the controller of Section 2. Although the controller regulates the distance between two vehicles considerably well (see Fig. 1), we evaluate the performance of the controller with relatively difficult condition to be regulated.

We first employ the system (2) in this study, instead of the system (5). By doing this we can directly input any arbitrary $v_l(t)$ for the time function of velocity of the leading vehicle, and we can test the controller via rapid acceleration/deceleration of $v_l(t)$, instead of the slowly decreasing $v_l(t)$ of the simulation in Fig. 1. Note that the function of the example in Fig. 1 is implemented by manipulation of $w_l$ of the system (5).

Thus we now rewrite the system (3) with $u = -k_1x_1 - k_2x_2 - k_3x_3 - k_4x_4$, in the following state space form

$$\dot{x} = A_c x + B_c x, \tag{7}$$

where

$$A_c = \begin{bmatrix} 0 & -1 & 0 & 0 \\ -k_1K_c/\tau_c & -(1+k_2K_c)/\tau_c & -k_3K_c/\tau_c & -k_4K_c/\tau_c \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}.$$

With this system (7) it is possible to simulate with arbitrary $v_l(t)$ in z.

In addition we consider time varying parameters in this section. Note that it is assumed that $\tau_c, \tau_l, K_c$, and $K_l$ are constant in Section 2. Also note that the controller has been designed based on the linearised model of vehicle longitudinal motion with these constant parameters.

However in reality the longitudinal motion dynamics are nonlinear. Consequently the system parameters of the linearised model might not be constant but vary due to the operating conditions. Thus it is reasonable to consider time varying parameters in order to deal with the nonlinearity of vehicle longitudinal dynamics.

For the controlled vehicle $\tau_c$ and $K_c$ are suggested by [18], namely

$$\tau_c(t) = \frac{m_c}{\rho C_d A(v_c(t) + u_w)},$$
$$K_c(t) = \frac{1}{\rho C_d A(v_c(t) + u_w)} = \frac{\tau_c(t)}{m_c}, \tag{8}$$

where $m_c$=1,000(kg), $\rho$ =1.202(kg/m$^3$), $C_d = 0.5$, A=1.5 (m$^2$) and $u_w$=0(m/sec) For example, if $v_c$=30 (m/sec), then $K_c$=0.037 and $\tau_c = 36.9754$ which have been employed in section 2. For the simulation example of Fig. 1, $K_c$ and $\tau_c$

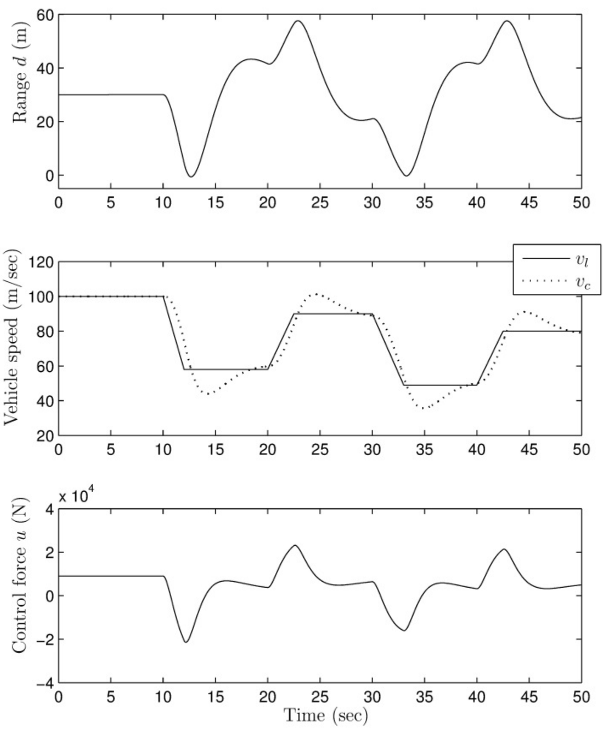


**Fig. 2.** Simulation result using the model (7) with the time varying parameters $\tau_c$ (t) and $K_c$(t), described in (8). The middle graph provides the function $v_l$(t) used in this simulation. The controller is the same with the simulation in Fig 1.

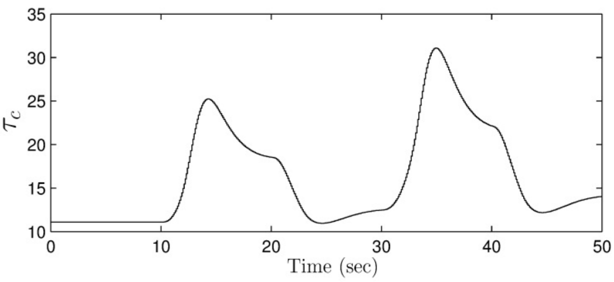


**Fig. 3**. Time varying parameter of the simulation in Fig. 2. $\tau_c$ (t) for the simulation is plotted. Note that $K_c$(t) is $\tau_c(t) / m_c$

are considered as constants and calculated with nominal value of vehicle velocity, $v_c$=30(m/sec).

Fig. 2. shows the simulation result with time varying parameters, $K_c(v_c)$ and $\tau_c$ ($v_c$), and the controller proposed in Section 2. We update the time varying parameters every a short time period *T* using (8) and we simulate the system (7) for the time period. This process is repeated until the simulation is terminated. In this simulation we set *T* =0.1 (sec).

$v_l$(t) is given in the middle graph of Fig. 2. This function describes significantly rapid acceleration/deceleration of the leading vehicle while the function $v_l$(t) shown in Fig. 1 does not. As illustrated on the top graph of Fig. 2 this simulation result shows implies collisions between the leading vehicle and the controlled vehicle at about 12.5 (sec) and 33 (sec). Note that non-positive value of *d* implies that the two vehicle bodies contact each other.

Fig. 3 depicts the time varying parameter $\tau_c(t)$ during the simulation of Fig. 2. Note that $K_c(t) = \tau_c(t) / m_c$ thus the graph for $K_c$(t) is omitted.

In the following section we will discuss how to improve the controller performance for the regulation of the range d to the level set by r = 30 (m).

## 4. Improvement of Controller Performance

In this section we propose a new design method for headway controller in order to improve the performance. One possible attempt to improve the control result in Fig. 2 is to re-design the controller repeatedly at the time instance when $\tau_c$ and $K_c$ are updated by the pole placement technique based on these updated parameters.

To implement this control scheme using Matlab, we suggest control procedure 1 described by the following steps.

**Implementation steps for control procedure 1**

**Initialization:** Select a positive number *T*(sec), the sampling time for the computation of the time varying parameters, $\tau_c$ and $K_c$. Select $s_i$, i ∈ {1, 2, 3, 4} which correspond to desired 4 poles for pole placement technique.

Finally $x_i$ is the initial condition of the system (2).

**STEP 1 :** Measure $v_c$(i.e. $x_1$) and then calculate, $\tau_c$ and $K_c$ by Eq. (8) with this measurement $v_c$ .

**STEP 2:** Obtain $A_a$ and $B_a$ by $\tau_c$ , $K_c$ and (4).

**STEP 3:** Compute the gains $K_i$, $i \in \{1, 2, 3, 4\}$ for feed-back control input *u*, using Matlab command place with $A_a$ ,$B_a$ , and $s_i$ , $i \in \{1, 2, 3, 4\}$.

**STEP 4:** Integrate the system (7) for *T* (sec) with initial co-ndition $x_i$ and $K_i$ , $i \in \{1, 2, 3, 4\}$. Let $x_f$ be the final va-lue of state vector of the integration.

**STEP 5:** Set $x_i = x_f$ and go to STEP 1.

The simulation result of this procedure is presented in Fig. 4. In the simulation for the pole placement we employ the poles $s_1$ , $s_2$ , $s_3$ , and $s_4$ , suggested in [18]. As mentioned in Section 1., in this paper we assume that the desired poles are given and we focus on the controller design method using pole placement technique for the given desired poles. Then the controller is renewed every time period $T = 0.1$(sec). Other simulation conditions, such as the function $v_1(t)$, are the same with those used in the simulation of Fig. 2.

Nonetheless, the simulation result of Fig. 4 is not easily distinguishable from that of Fig. 2. Note that the scales of the graphs in Fig. 4 are the same with those in Fig. 2.

In order to show the difference between these two control results we provide the difference of the ranges *d* in Fig. 5. $d_R(t)$, in Fig. 5 is given by

$$d_R(t) = d_1(t) - r(t)_2 - d_2(t) - r(2)_2 \tag{9}$$

where $d_1(t)$ and $d_2(t)$ are the ranges d(t) in Fig. 2 and Fig. 4, respectively, and $r = 30$.

A positive value of $d_R(t)$ at time *t* implies that the control idea implemented in Fig. 4 regulates the range at time *t* closer to *r* than that in Fig. 2. From Fig. 5 we can see that the controller performance of Fig. 4 is improved for most simulation time.

There is no collision between the two vehicles for the simulation of Fig. 4 since $d_2(t) > 0$ for $0 \le t \le 50$, while there are a couple of collisions for the simulation of Fig. 2.

However the difference between Fig. 2 and Fig. 4 is hardly distinguished. In the following section we suggest a control method which can improve the regulation performance much more.

### 4.1 Design approach with linear time varying system

In order to derive new design method for the improvement of controller performance we first remind that $v_1(t)$ is considered as noisy disturbance which should be rejected by the control methods in Fig. 2 and Fig. 4.

However we should note that $v_1(t)$ is the function describing the longitudinal velocity of the leading vehicle, thus normally, compared to white noise signal, it can be considered as slowly varying function of time. Accordingly,

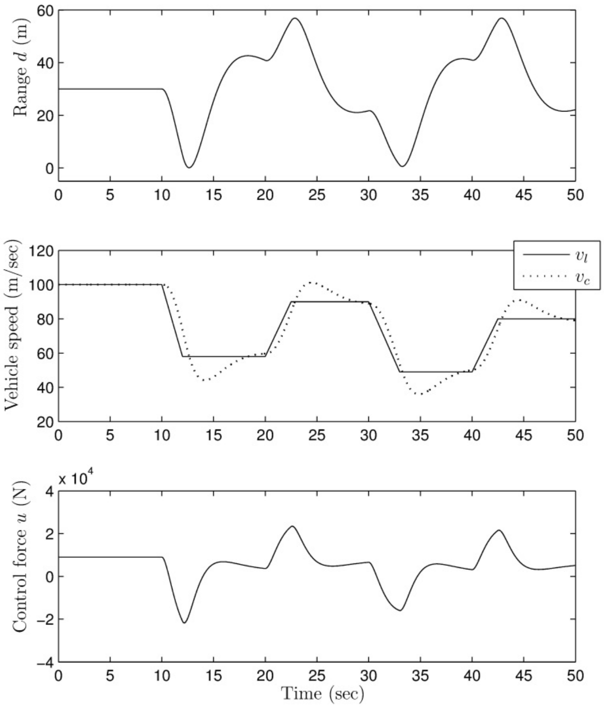


**Fig. 4.** Simulation result with the controller that is redesigned iteratively by pole placement whenever the time-varying parameters are renewed. Other simulation conditions, such as the function $v_1(t)$, and the poles for the implementation of pole placement, are the same with those used in the simulation of Fig. 2.

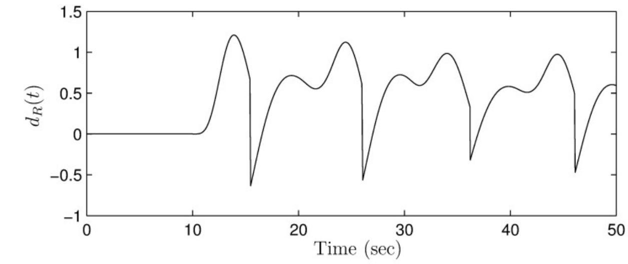


**Fig. 5.** Graph of $d_R(t)$ in (9) where $d_1(t)$ and $d_2(t)$ are the ranges $d(t)$ in Fig. 2 and Fig. 4, respectively. This graph shows that the controller of Fig. 4 regulates the range *d* closer to *r* than that of Fig. 2 for most simulation time.

if we employ sufficiently small sampling time *T*, this signal $v_1(t)$ is maintained as approximately constant level for each time *T*(sec). We here suggest a controller design method with which we considers $v_1(t)$ as virtually constant disturbance for the plant system (2) for each *T* (sec). This approach is implemented by the structure for the iterative renewal of the time varying parameters, so we design a new controller at each sampling time *T*(sec) depending on $v_1(t)$ as well as $\tau_c(t)$ and $K_c(t)$ as implemented in the control procedure 1.

To this end we introduce the following matrix $\tilde{A}_a(n)$

to express the disturbance for $T$ (sec) of the system (2), corresponding to $v_l(t)$, by time varying parameter in the matrix

$$\tilde{A}_a(n) = A_a + V(n), \tag{10}$$

where V(n), n ∈ {1, 2, 3, 4} is a 4×4 matrix of which all elements are zero, except (1, $n$)-th element is defined as vl/xn.

Then we can convert system (3) into the following system with $\tilde{A}_a(n)$ in (10),

$$\begin{aligned}\dot{x} &= A_a x + B_a u + B_c \\ &= A_a x + B_a u + [1 \quad 0 \quad 0 \quad 0]^T v_l + \tilde{B}_c \tilde{z} \\ &= A_a x + B_a u + v(n)x + \tilde{B}_c \tilde{z} \\ &= \tilde{A}_a(n)x + B_a u + \tilde{B}_c \tilde{z},\end{aligned} \tag{11}$$

where $\tilde{z} := [r, w_c]^T$ and

$$\tilde{B}_c = \begin{bmatrix} 0 & 0 \\ 0 & K_c/\tau_c \\ -1 & 0 \\ 0 & 0 \end{bmatrix}.$$

By similar way we could define $\tilde{B}_a$ to describe the system bias induced by $v_l(t)$ while we only consider $\tilde{A}_a(1)$ in this paper. Note that we examine the system offset with $\tilde{A}_a(1)$ in this research thus we employ

$$\tilde{A}_a(1) = \begin{bmatrix} v_l/x_1 & -1 & 0 & 0 \\ 0 & -1/\tau_c & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \tag{12}$$

to compute the gains $k_i$, i ∈ {1, 2, 3, 4}, instead of $A_a$. Particularly note that $\tilde{A}_a(2)$ must be problematic when $v_c$ and $v_l$ converge to each other. This is because it renders all elements in the first row of $\tilde{A}_a(2)$ to be nearly zero and $\tilde{A}_a(2)$ becomes almost uncontrollable.

Now in order to exploit the time varying matrix $\tilde{A}_a$ in (12) we suggest control procedure 2 described by the following steps.

**Implementation steps for control procedure 2**

**Initialization:** Select a positive number T (sec), and $s_i$, $i \in \{1, 2, 3, 4\}$. In addition $x_i$ is the initial condition of the system (2).

**STEP 1 :** Measure $v_l$ and v. Then calculate $\tau_c$ and $K_c$ by Eq. (8) with the measurement $v_c$.

**STEP 2 :** Obtain $A_a$ and $B_a$ by $\tau_c$, $K_c$ and Eq. (4). Then compute $\tilde{A}_a(1)$ by $A_a$, $x_i(1)$, the measured $v_l$, and

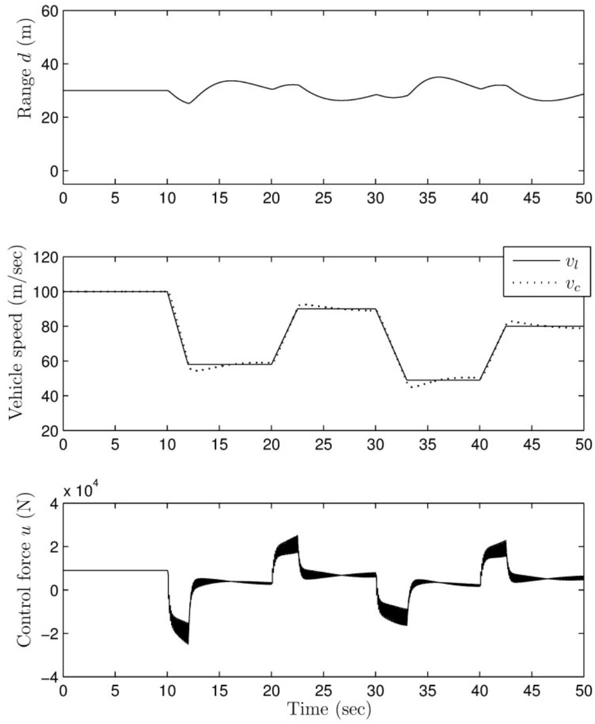


**Fig. 6.** Simulation result with the control procedure summarized in Section 4.1. The scales of this figure are the same with those in Fig. 2 and Fig. 4. This controller regulates the range $d$ significantly close to $r$ = 30 (m), compared to the controllers in Fig. 2 and Fig. 4.

Eq. (12).

**STEP 3:** Compute the gains $k_i$, $I \in \{1, 2, 3, 4\}$ for feedback control input u, using Matlab command place with $\tilde{A}_a(1)$, $B_a$, and $s_i$, $i \in \{1, 2, 3, 4\}$.

**STEP 4:** Integrate the system (7) for T (sec) with initial condition $x_i$ and $k_i$, $i \in \{1, 2, 3, 4\}$. Let $x_f$ be the final value of state vector of the integration.

**STEP 5:** Set $x_i = x_f$ and go to STEP 1.

The control procedure 2 is mostly based on the control procedure 1 but it includes some modification on the STEP 1, 2, and 3.

Fig. 6 illustrates the simulation result with the control procedure 2. Note that the scales of the graphs in Fig. 6 are the same with those in Fig. 2 and Fig. 4 in order to compare these controller simulations easily and to emphasise the improved regulation of inter-vehicle distance by the control scheme proposed in this section.

The suggested controller regulates the range of intervehicle distance significantly close to $r$ = 30 (m) and the control result is far from collision between the two vehicles, compared to the results in Fig. 2 and Fig. 4. In addition, the magnitude range of control force $u$ required by this controller design approach is almost the same with the previous ones in Fig. 2 and Fig. 4.

## 5. Discussions and Conclusions

In this paper we have researched how to design a cruise controller with respect to distance to vehicle ahead. We have employed linear time varying (LTV) model for the longitudinal vehicle dynamic motion. With this LTV system we have approximately modeled the nonlinear dynamics of vehicle speed by frequent update of the system parameters.

In addition we have reformulated the LTV system by changing distance to leading vehicle into variation of system parameters of the model. Note that in conventional control problem formulation this distance is considered as disturbance which should be rejected. As a result a new controller can be obtained by pole placement at each renewal of parameters, based on the linear model with the present system parameters. The effectiveness of the design method has been illustrated by simulation examples. We conclude this paper with the following additional remark.

### 5.1. Future research direction

Although the control methods shown in Fig. 2 and Fig. 4 only need the measurements of inter-vehicle distance *d* and controlled vehicle velocity $v_c$, the control method proposed in Section 4.1. additionally requires the measurement of leading vehicle velocity $v_l$.

Note that we can approximate $v_l(t)$ based on the measurements of $v_c(t)$, $d(t)$, and $d(t-\Delta t)$ where $\Delta t$ is a sufficiently small positive number. Accordingly we can modify the control procedure in Section 4.1. in order to employ approximation of leading vehicle speed, instead of $v_l(t)$. Then we need to analyse this modified control scheme further, such as the effect on the control performance by the number $\Delta t$.

In addition we assume that $r=30$(m) and $w_c=0$ for the case studies of this paper, as suggested in [18]. Thus in the next stage of this research we will examine the control methodology of this paper considering r and $w_c$ as functions of time and will develop the control method further with regard to time varying $\tilde{z}(t)$ in (11).

Also note that the longitudinal motion dynamics of automobile are nonlinear in reality, while we research the dynamics based on linearised models and linear system simulation (e.g. Matlab command lsim) throughout this paper. For the linearised models the control methods mentioned in this paper guarantee stability of the controlled linear systems since pole placement technique is applied to controllable systems [20]. As the next step of research we will analyse the stability of nonlinear dynamic model with our control scheme as well as nonlinear system simulation study.

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