

Road Vehicle Following Control Strategy Using Model Reference Adaptive Control Method Stability Approach

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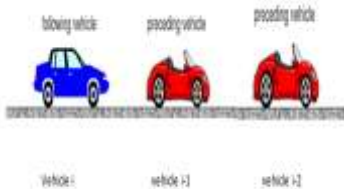
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Graphical abstract



Abstract

In convoy system, the control system on each vehicle requires information about preceding vehicle motion, in order to maintain stability and satisfy operating constraints. A two-vehicle look-ahead control strategy is proposed and investigated for the operation of a convoy. The mathematical modeling for this control strategy has been formulated and simulated in this paper. This paper demonstrates the design process of an adaptive controller gain for a road vehicle following system. This process is done by simulation. The appropriate constants are used as the reference model for the adaptive controller implementation to find the effectiveness of the control. As a result, a road vehicle following system with an adaptive gain controller is produced.

Keywords: Two-vehicle look-ahead control strategy, model reference adaptive control, Stability approach

Abstrak

Dalam sistem konvoi, sistem kawalan pada setiap kenderaan memerlukan maklumat mengenai pergerakan kenderaan di hadapannya bagi mengekalkan kestabilan dan memenuhi kekangan operasi. Strategi kawalan dengan melihat dua-kenderaan di hadapan adalah dicadangkan dan operasinya dalam konvoi diselidiki. Permodelan matematik bagi strategi kawalan ini telah diformulasi dan disimulasikan dalam kertas kerja ini. Kertas kerja ini juga memaparkan proses merekabentuk suatu gandaan pengawal adaptif bagi sistem pengekoran kenderaan jalanraya. Proses merekabentuk ini dilakukan menggunakan simulasi komputer. Pemalar bersesuaian digunakan sebagai model rujukan bagi implementasi pengawal adaptif yang menghasilkan kawalan sistem yang berkesan. Ini menghasilkan sistem pengekoran kenderaan jalanraya yang mempunyai suatu pengawal gandaan adaptif.

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1.0 INTRODUCTION

Nowadays, problems related to traffic congestion is addressed as issue which has to be considered, since this issue continuously causes many accidents, traffic jams and so on. Convoys or platoons has been introduced and developed rapidly in order to overcome the collision. One of the matter which has to be taken into careful consideration in road convoy system formulation is the speed and the spacing of the following vehicle with respect to the preceding vehicle. It is important to maintain some safe distance between the following vehicle and preceding vehicle at any speed in convoy system in order to avoid any collision between both of them [1].

Sensors are used to measure the speed and the position of the preceding vehicle instead of estimating the information by the driver [2]. The information which has been gotten by the sensor is used and processed by the following vehicle controller to produce the amount of required speed and safe spacing distance. Basically in autonomous control approach, safe distance can be ensured

automatically by using a controller based on the information obtained from the preceding vehicle. The autonomous controller on the following vehicle has the ability of activating of the vehicle cruise control mode. In this case it does not need to hold the steering nor press the fuel pedal by the driver, and automatically apply the brake when necessary in order to ensure the safety of the vehicle. In fact, research in vehicle convoy has attracted the attention of several researchers in the past decades, particularly in the USA and Europe where safety, energy consumption and traffic congestions are the primary motivators. Major contributions are from the Chauffeur Project (Europe), the PATH program (USA), the Intelligent Transportation System program in Japan and the Cyber Car project in France [1,3]. Although of some theoretical interest in the early 1970's, it has taken the severe traffic near around major urban centres in the late 1980's to rekindle interest around the world [4]. In developed nations, the autonomous concept leads to the Intelligent Vehicle Highway System (IVHS). As a vehicle enters the highway, his vehicle automatically takes-over the control of the vehicle while

following the preceding vehicle. This feature also gives rise to steering less technology where during the autonomous control in action, the driver does not need to hold the steering wheel. All the driving tasks are taken care by the vehicle intelligent system. One of the autonomous features is the adaptive type control based on certain control strategy which gives rise to adaptive cruise control (ACC). An ACC controlled vehicle will follow the front vehicle at a safe distance. A Model Reference Adaptive Control (MRAC) can be used in this type of control where the vehicle controller has the ability to adapt to the variation of speed and position of the preceding vehicle[3].



Figure 1 Diagram of a road vehicle convoy system

2.0 EXPERIMENTAL

2.1 Two-Vehicle Look-Ahead Control Strategy

In convoy s system, when one vehicle follows two preceding vehicle, the system is formed as shown in(Fig.1).The following vehicle control consists of one of the two ways: either maintain the speed of the following vehicle as same as the speed of two immediate preceding vehicles or maintain a safe distance among them in order to avoid any collisions. This is where the string stability plays an important role by having a string stable vehicle convoy system[5].The system is said to stable if the range errors decrease as they propagate along the vehicle stream.

In this control strategy, the controlled vehicle receives the information from the preceding vehicle and the one in front of the preceding vehicle. So, the control system on the following vehicle needs information about the motion of preceding vehicles.

As Yanakiev and Kanellakopoulos used in their work[6],they used a simple spring-mass-damper system to demonstrate the idea of string stability and show the string-stability criterion for constant time headway and variable time-headway policies. So from the actual diagram in Fig. 1, the vehicle following system can be represented a mass-spring-damper analogy[7]as shown in Fig. 2. A mathematical model for this control strategy is shown in Fig. 2 where it represents the following vehicle, i-1 represents the immediate preceding vehicle, and i-1 represents the vehicle which is in front of preceding vehicle. The parameters in the above figure are vehicle mass (m),vehicle displacement (x), vehicle acceleration (\ddot{x}), spring constant (k_p) and damper constant (k_v). The interest is only on the following vehicle. So, performing the mathematical modeling on only the following vehicle i and applying the Newton’s Second law results in the following Eq. (1).

$$m\ddot{x}_i = K_{p1}(x_{i-1} - x_i) + K_{p2}(x_{i-2} - x_i) + K_{v1}(\dot{x}_{i-1} - \dot{x}_i) + K_{v2}(\dot{x}_{i-2} - \dot{x}_i) \quad (1)$$

By assuming unit mass for Eq. (1) and taking Laplace transform, gives the following transfer function.

$$x_i = \frac{(K_{v1}s + K_{p1})x_{i-1} + (K_{v1}s + K_{p2})x_{i-2}}{s^2 + [K_{v1} + K_{v2}]s + K_{p1} + K_{p2}} \quad (2)$$

The transfer functioin Eq. (2) depends on the following spacing policy.

The aim of this strategy is to maintain string stability for longitudinal motion within the vehicle following system or the

vehicle convoy, particularly between a vehicle with a vehicle or between vehicles with a following vehicle. This strategy is adopted in order to design a controller by investigating the following two policies

2.2 Spacing Policy

A spacing policy is defined as a rule that dictates how the speed of an automatically controlled vehicle must regulate as a function of the following distance. A control system should be designed such that it regulates the vehicle speed according to the designed spacing policy[8]

2.2.1 Fixed Distance Spacing Policy

This type of spacing policy keeps a constant inter-vehicular spacing regardless to the convoy’s speed. A well-known result states that it is impossible to achieve string stability in autonomous operation when this spacing policy is adopted[9]. The main reason of this impossibility is because the relative spacing error does not attenuate as it propagates down the convoy at all frequencies. Spacing error attenuation will only occur for frequencies above certain level as described in[9]. In addition, keeping the same fixed spacing at different convoy speed would be risky for safety and comfort of passengers, especially when the vehicles are closely separated. Furthermore, keeping the same constant spacing at different convoy speed would risk the safety and comfort of passengers, especially when the vehicles are closely separated. Obviously, at higher speed, faster vehicle reaction time is needed in emergency situation to avoid collision. Despite of this [9]and[10]showed that the constant spacing policy can give guaranteed string stability if the lead vehicle is transmitting its speed and/or acceleration to all following vehicles in the convoy and this can be done through radio communication. More to the point, String stability is a property that ensures spacing errors between vehicles do not grow as they propagate along the convoy [11]. Obviously, at higher speed, faster vehicle reaction time is needed in an emergency situation to avoid collision. Nevertheless, the fixed spacing policy can give guaranteed string stability if the front vehicle provides its information on its speed and/or position to the rear vehicle in the convoy[12].This can be done through radio communication or the rear vehicle having sensors to detect the above two parameters. Moreover,Eq. (2) represents the transfer function for the fixed spacing policy.

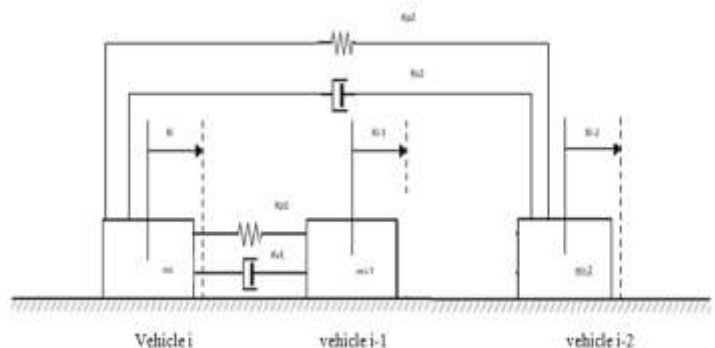


Figure 2 A mathematical model of a vehicle convoy system control strategy

2.2.2 Fixed Time Headway Policy

This policy use a constant time interval of inter-vehicular spacing, called time headway between the following vehicle and preceding vehicle. It is a speed dependent policy where the inter-vehicular

spacing will vary according to the preceding vehicle speed. At higher speed, vehicles will be separated in a greater distance but always maintains a fixed time interval between vehicles. Most researchers used this spacing policy in designing controllers to ensure the string stability, as well as this policy mimics the behavior of human drivers. As vehicle speed is increased, a human driver will keep a safe inter-vehicular spacing with the immediate preceding vehicle.

Equation (1) also shows the model with fixed spacing policy. It has been shown in [13] that a fixed spacing policy could not ensure string stability in a vehicle convoy system. This is due to the fact that different inter-vehicle spacing is needed for different convoy speed, in order to maintain enough time for the following vehicle to react.

The performance of the fixed headway spacing policy used in autonomous and cooperative vehicles following systems has been studied[14]. It is found that there exists minimum possible fixed headway spacing before the string stability of convoy collapses, which is related to the actual dynamics of the vehicle. The effect of this fixed headway spacing policy is equivalent to the introduction of additional damping in the transfer function, which allows the poles of the transfer function to be moved independently from the zeros of the same transfer function. With the addition of the fixed headway spacing, Eq. (2) then becomes

$$x_i = \frac{(K_{v1}s + K_{p1})x_{i-1} + (K_{v1}s + K_{p2})x_{i-2}}{s^2 + [K_{v1} + K_{v2} + (K_{p1} + 2K_{p2})h]s + K_{p1} + K_{p2}} \quad (3)$$

and the control law developed as:

$$u_i = K_{p1}(x_{i-1} - x_i - h\dot{x}_i) + K_{p2}(x_{i-2} - x_i - 2h\dot{x}_i) + K_{v1}(\dot{x}_{i-1} - \dot{x}_i) + K_{v2}(\dot{x}_{i-2} - \dot{x}_i) \quad (4)$$

Equation (4) can be re-arranged and reduced to a single pole system as follows,

$$x_i = \frac{K_{v1}(s + \frac{K_{p1}}{K_{v1}})x_{i-1} + K_{v2}(s + \frac{K_{p2}}{K_{v2}})x_{i-2}}{s^2 + (K_{p1} + 2K_{p2}) + K_{v1}(s + \frac{K_{p1}}{K_{v1}}) + K_{v2}(s + \frac{K_{p2}}{K_{v2}})} \quad (5)$$

To simplify the control law and at the same time ensure stability, a pole-zero cancellation technique is chosen. This can be achieved by introducing the constraint

$$\frac{K_{p1}}{K_{v1}} = \frac{K_{p2}}{K_{v2}} = (K_{p1} + 2K_{p2})h \quad (6)$$

$$x_i = X \frac{K_{v1}x_{i-1} + K_{v2}x_{i-2}}{s + K_{v1} + K_{v2}} \quad (7)$$

This is a first order system. Since K_{v1} and K_{v2} are always positive, the pole of equation (7) is always on the left hand side of the s-plane and the system is always stable under the constraint of equation (6). Hence, the mathematical model of the proposed vehicle convoy system in equation (4) is string stable under the constraint of equation (6).

2.3 Vehicle Dynamic Consideration

After having proved that the fixed time headway policy is suitable to be adopted, a simplified vehicle dynamics model is introduced in order to mimic the actual vehicle internal dynamics. In this case, the external dynamics is not considered. In the simplified model, the internal dynamics is represented as a lag function i.e., [15]the actual vehicle acceleration is obtained after a certain time delay. This is given by the relation in equation (8)[15].

$$\tau \dot{a} + a = u \quad (8)$$

Eq. (3) is modified to include the vehicle dynamics part and this gives a transfer function in Eq. (9).

$$x_i = Xi = \frac{(K_{v1}s + K_{p1})x_{i-1} + (K_{v1}s + K_{p2})x_{i-2}}{s^2(\tau s + 1) + [K_{v1} + K_{v2} + K_{p1} + 2K_{p2}]h]s + K_{p1} + K_{p2}} \quad (9)$$

With the inclusion of the vehicle dynamics, the control signal derived from the one vehicle look ahead control strategy is fed to drive the vehicle dynamics in order to produce the vehicle acceleration. Block diagram consisting of the control strategy and vehicle dynamics is shown in Fig.3 .

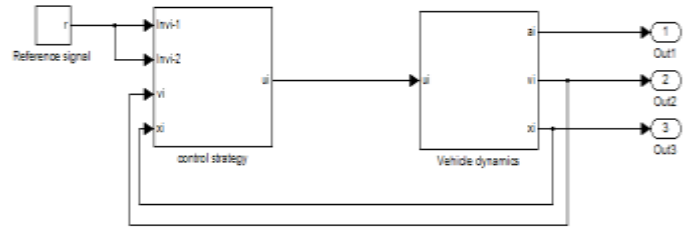


Figure 3 Block diagram consisting of the control strategy and vehicle dynamics

τ is too small i.e. $\tau \rightarrow 0$, then $s^3 = 0$. The transfer function is thus reduced to a second order transfer function shown in equation (10).

$$x_i = X \frac{(K_{v1}s + K_{p1})x_{i-1} + (K_{v1}s + K_{p2})x_{i-2}}{s^2 + [(K_{v1} + K_{v2} + K_{p1} + 2K_{p2})h]s + K_{p1} + K_{p2}} \quad (10)$$

2.4 Model Reference Adaptive Control

An adaptive controller can modify its behavior in response to changes in the dynamics of a system and the character of any disturbance. It is a controller with adjustable parameter and a mechanism for adjusting the parameter. An adaptive control system consists of two loops, normal feedback loop with plant and controller and an adaptive parameter mechanism loop. Figure 4 illustrates the general structure of the Model Reference Adaptive Control (MRAC) system. The basic MRAC system consists of four main components:

- i) Plant to be controlled
- ii) Reference model to generate desired closed loop output response
- iii) Controller that is time-varying and whose coefficients are adjusted by adaptive mechanism
- iv) Adaptive mechanism that uses ‘error’ (the difference between the plant and the desired model output) to produce controller coefficient.

Regardless of the actual process parameters, adaptation in MRAC takes in the form of adjustment of some or all of the controller coefficients so as to force the response of the resulting closed-loop control system to that of the reference model. Therefore, the actual parameter values of the controlled system do not really matter.

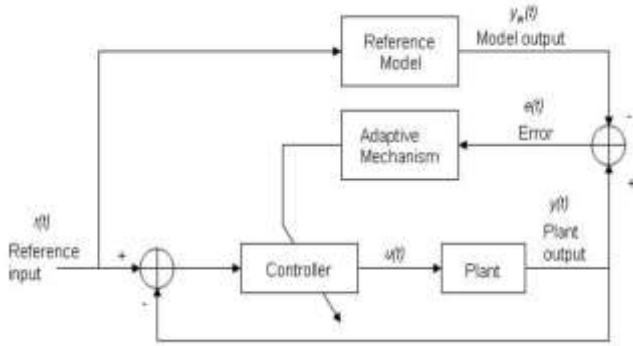


Figure 4 General structure of an MRAC system

2.4.1 Model Reference Adaptive Control

The equilibrium point globally asymptotic stability of the error difference equation can be guaranteed by design the MRAC stability approach or Lyapunov second approach .The term Lyapunov approach is used throughout this paper. It requires an appropriate Lyapunov function to be chosen, which could be difficult. This approach has stability consideration in mind and is also known as the Lyapunov approach.

It is desired, in the design of MRAC controller, the output of the closed loop system(y) to follow the output of the reference model(y_m).as a result the aim is to minimize the error(e=y-y_m).

2.4.2 Adaptive Controller Gain Design

An adaptive controller gain is to be designed for the two vehicle look-ahead control strategy with fixed time headway and vehicle dynamics by applying a Model Reference Adaptive Control (MRAC) stability approach. This section presents a direct adaptive controller design which adapts the unknown vehicle parameters K_{p1} and K_{p2} .The advantage of the adaptive approach is that unpredictable changes in the value of $K_{p1}k$ and $K_{p2}kp2$ can be easily accommodated. From the analysis of Figure 7 and Figure 8, $K_{p1}k=K_{v1}kv1=0.28$ and $K_{p2}kp2=K_{v2}kv2=0.36$ give the best response. So, it will be used in equation (10) to produce a reference model in equation (12) to be used in designing the adaptive controller gain. The vehicle dynamic has been included in the control law to form the plant. The reference model is represented as in eq. (12).

By considering $K_{p1}=K_{v1}Kp1=kv1=K_1 k1$ and

$K_{p2}=K_{v2}=K_2 Kp2=Kv2=k2, x_{i-1} = r_1, x_{i-2} =r_2, x_i=y$, so the plant will be as in eq.(11):

$$x_i = \frac{K_1 (s+1)x_{i-1} + K_2 (s+1)x_{i-2}}{s^2 + (2K_1 + 3K_2)s + (K_1 + K_2)} \tag{11}$$

And the reference model will be:

$$x_i = \frac{0.28 (s+1)x_{i-1} + 0.36(s+1)x_{i-2}}{s^2 + 1.64s + 0.64} \tag{12}$$

A closed loop system with a controller has the following parameters:

$r(t)$ = Reference input signal

$u(t)$ = Control signal

$y(t)$ = Plant output

$y_m(t)$ = Reference model output

$e(t)$ = Difference between plant and reference model output

$e = y(t) - y_m(t)$

$$e = y - y_m$$

2.4.3 The Lyapunov Approach Design

In designing an MRAC using Lyapunov Method, the following steps should be followed:

i)Derive a differential equation for error, $e = y - y_m$ (i.e. \dot{e} , \ddot{e} etc.) that contains the adjustable parameters $K_{p1}kp1$ and $K_{p2}kp2$ From Equation (11) and (12), after replacing, the differential equation becomes

$$y \ddot{=} -2k_1\dot{y} -3k_2\dot{y} - k_1 y - k_2 y + k_1 r_1 + k_2 r_2 \tag{13}$$

$$y_m \ddot{=} -1.64\dot{y}_m -0.64y_m + 0.28r_1 + 0.36 r_2 + 0.28 r_1 + 0.36 r_2 -2k_1.64 -0.64y_m + 0.28 + 0.36 + 0.28r_1 + 0.36 r_2 \tag{14}$$

$$\ddot{e} = \dot{y} - y_m \ddot{=} \tag{15}$$

Substituting equations (13) and (14) in (15)

$$\begin{aligned} \ddot{e} &= -2k_1\dot{y} -3k_2\dot{y} -k_1 y - k_2 y + k_1 r_1 + k_2 r_2 + \\ & 1.64\dot{y}_m + 0.64y_m - 0.28r_1 -0.36 r_2 - 0.28 r_1 - 0.36 r_2 \\ \ddot{e} &= -2k_1\dot{y} -3k_2\dot{y} - k_1 y - k_2 y + k_1 r_1 + k_2 r_2 + \\ & 1.64 \dot{y} - 1.64\dot{e} + 0.64y - 0.64e - 0.28r_1 -0.36 r_2 - 0.28 r_1 - 0.36 \\ & r_2 + 0.64y - 0.64e - 0.28r_1 - 0.36 r_2 - 0.28 r_1 - 0.36 r_2 + 0.64y \\ & - 0.64e - 0.28r_1 -0.36 r_2 - 0.28 r_1 - 0.36 r_2 \\ \ddot{e} &= K_1 (-2\dot{y} - y + r_1 + r_1) + K_2 (-3\dot{y} - y + r_2 + r_2) + 1.64 \dot{y} - \\ & 1.64\dot{e} + 0.64 y - 0.64e - 0.28r_1 -0.36 r_2 - 0.28 r_2 - 0.36 r_2 \end{aligned} \tag{16}$$

Let's $K_1 = X_1$ and $K_2 = X_2$

$$\begin{aligned} \ddot{e} &= X_1 (-2\dot{y} - y + r_1 + r_1) + X_2 (-3\dot{y} - y + r_2 + r_2) + 1.64 \dot{y} - 1.64\dot{e} \\ & + 0.64 y - 0.64 - 0.28r_1 - 0.36 r_2 - 0.28 r_1 - 0.36 r_2 \\ & = = k_1 (-2- y +) + K_2 (-3- y +) + =x_1 (-2- y +) + x_2(-3- y +) + \end{aligned} \tag{17}$$

ii) Find a suitable Lyapunov function, usually in a quadratic form (to ensure positive definiteness).

The Lyapunov function, $V(\dot{e}, e, X_1, X_2)$, is based on equation(17).

$$V = \lambda_i \dot{e}^2 + \lambda_{ii} e^2 + \lambda_{iii} X_1^2 + \lambda_{iv} X_2^2$$

Where $\lambda_i, \lambda_{ii}, \lambda_{iii}, \lambda_{iv} > 0$, so that V is positive definite.

The derivative of V becomes;

$$\dot{V} = 2 \lambda_i \dot{e} \ddot{e} + 2 \lambda_{ii} e \dot{e} + \lambda_{iii} X_1 \dot{X}_1 + \lambda_{iv} X_2 \dot{X}_2$$

$$\begin{aligned} \dot{V} &= 2 \lambda_i \dot{e} (X_1 (-2\dot{y} - y + r_1 + r_1) + X_2 (-3\dot{y} - y + r_2 + r_2) + 1.64 \dot{y} \\ & - 1.64\dot{e} + 0.64 y - 0.64e - 0.28r_1 - 0.36 r_2 - 0.28 r_1 - 0.36 r_2) + \\ & \lambda_{ii} e \dot{e} + \lambda_{iii} x_1 \dot{x}_1 + \lambda_{iv} x_2 \dot{x}_2 \end{aligned} = 2(18)$$

Where for stability \dot{V} must be negative i.e. $\dot{V} < 0$

iii) Derive an adaptation mechanism based on $V(\dot{e}, e, X_1, X_2)$ such that e goes to zero.

$$\dot{X}_1 = - \frac{\lambda_i}{\lambda_{iii}} \dot{e} (-2\dot{y} - y + r_1 + r_1)$$

$$\dot{X}_2 = - \frac{\lambda_i}{\lambda_{iv}} \dot{e} (-3\dot{y} - y + r_2 + r_2)$$

$$= (-2- y +) = (-3- y +)$$

Since $K_1 = K_{p1} = X_1$ and

$K_2 = K_{p2} = X_2$, Therefore,

$$K_{p1} = - \lambda_1 e (-2\dot{y} - y + r_1 + r_1) \tag{19}$$

$$K_{p2} = - \lambda_2 e (-3\dot{y} - y + r_2 + r_2) \tag{20}$$

Figure (5) shows the simulation block diagram of Lyapunov approach adaptive control used for tuning of controller gains (k_{p1} and k_{p2}) where γ is denoted by gamma in the simulation diagram. Figure (6) shows the adaptive mechanism block diagram.

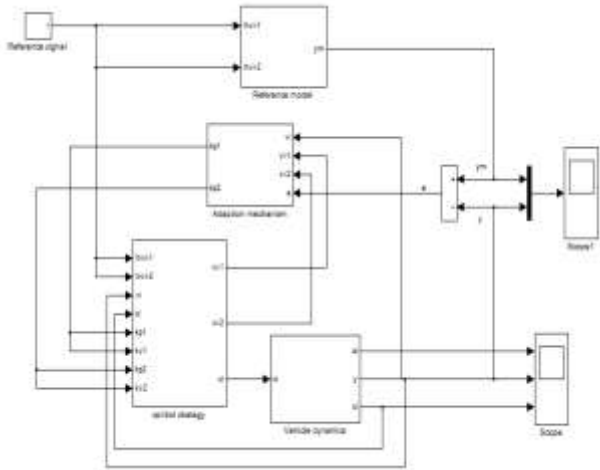


Figure 5 The Lyapunov approach adaptive gain controller simulation diagram

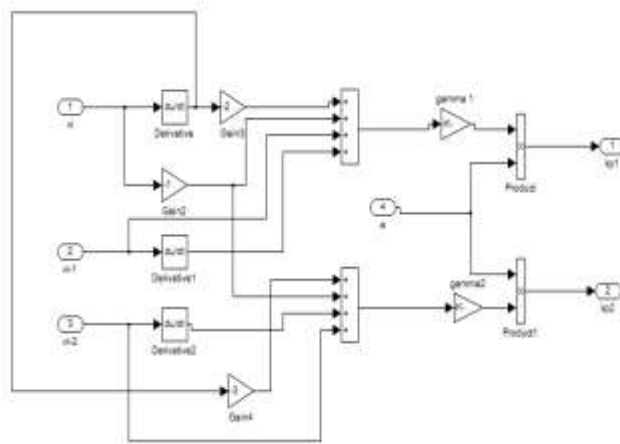


Figure 6 Simulation diagram of adaptive mechanism

3.0 RESULTS AND DISCUSSION

Eq. (10) is then simulated by using MATLAB Simulink with the set values of $h=1$ second with the values of K_{p1} which is equal to K_{v1} set as 0.28, 0.34, and 0.42 respectively and K_{p2} which is equal to K_{v2} set 0.36,0.33 and 0.29 respectively. The results are shown in Figures.7and Figure.8. There are some ripples or oscillations observed in the speed and acceleration plots. It is found that the values of $K_{p1} 1=0.28$ and $K_{p2} 2=0.36$ are still found to give the best result. This is still acceptable as the plots somehow show the real situation when the vehicle internal dynamics is taken into consideration.

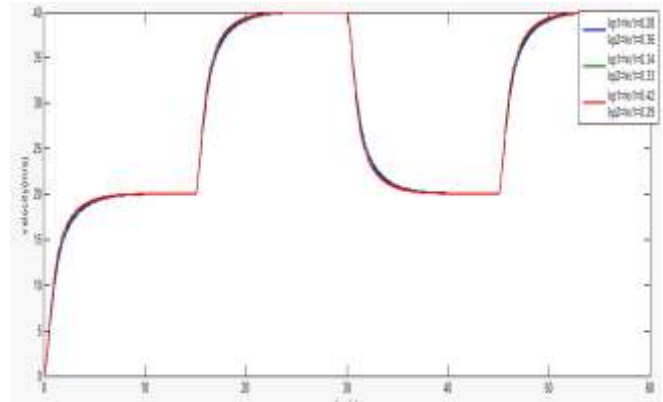


Figure 7 Speed response with fixed time headway for various K_p, k_v values and vehicle dynamics

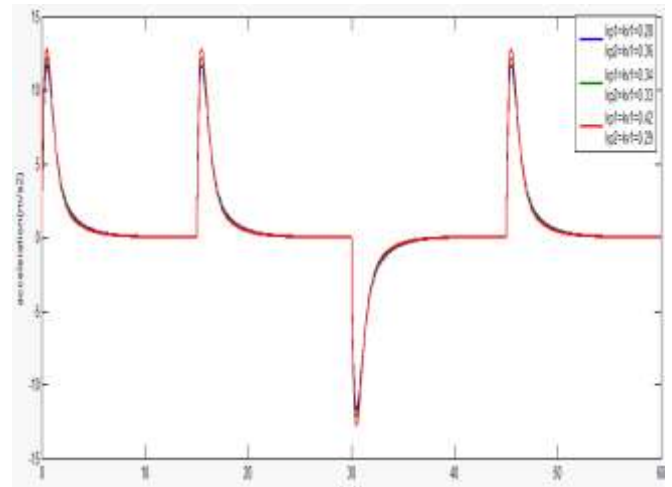


Figure 8 Acceleration response with fixed time headway for various K_p, k_v values and vehicle dynamics

The MRAC Lyapunov approach adaptive controller gain design is then simulated again using MATLAB Simulink. Both the output of the system responses (y and y_m) are shown in Figure9 and Figure 10. Figure 9 shows a perfect model following output while Figure 10 on the other hand shows the acceleration response of y where it does not follow a sharp change in input acceleration.

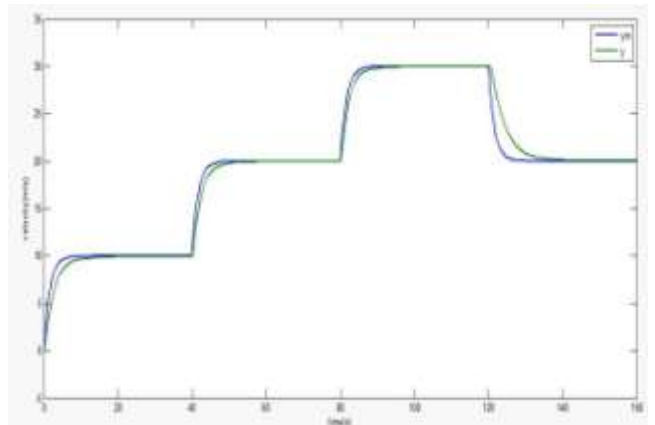


Figure 9 Comparison of y and y_m for speed from the Lyapunov approach

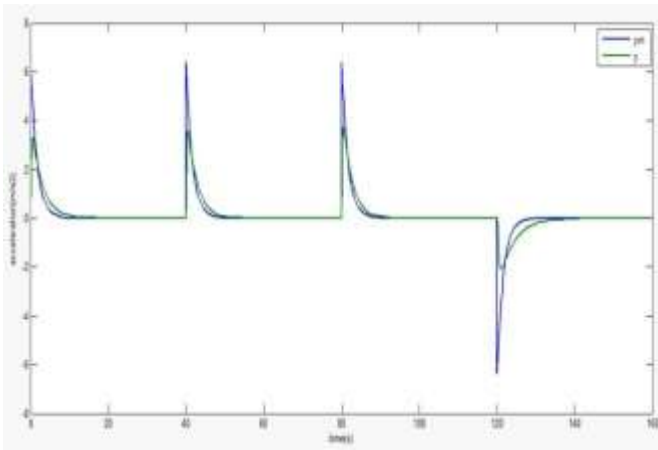


Figure 10 Comparison of y and y_m for acceleration from the Lyapunov approach

In Lyapunov approach better value of gamma which gives perfect result for each of speed and acceleration is when gamma equals to 0.5, 0.7 and 1. Eventually, the adaptive controller gain has been simulated with gamma value different gamma values in suitable range and with fixed value of h which is 2. The speed and acceleration response is shown in figure 11 and figure 12 respectively.

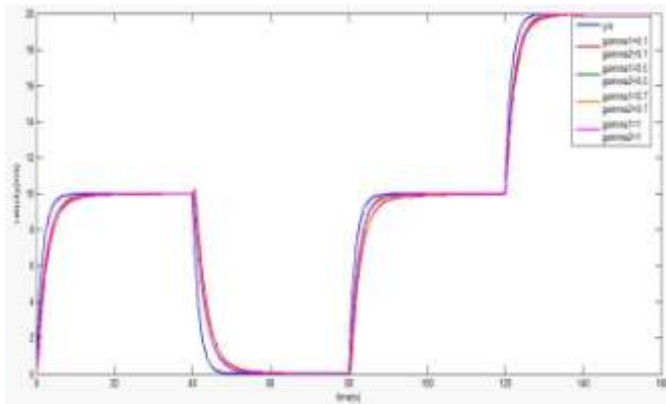


Figure 11 Speed response with various gamma values for adaptive gain controller

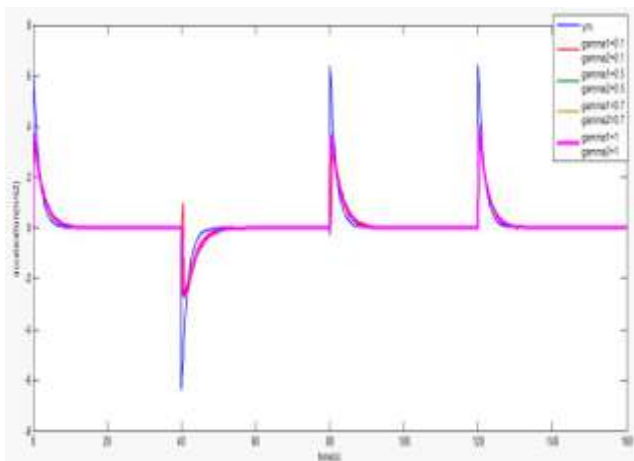


Figure 12 Acceleration response with various gamma values for adaptive gain controller

Figure 11 and figure 12 shows the speed and acceleration of adaptive controller gain, respectively. From additional analysis of Figure 12, it can be said that best response can be gotten when gamma value is 1, which gives the response that almost fitting the reference model with smooth curve. A two-vehicle look ahead control strategy with fixed headway policy has been investigated in designing a controller to produce an output that immediately can respond to the change in input. The input is considered the speed with varying speed conditions. With normal controller, the gain was tuned manually by try and error in order to find acceptable response and that method takes much time until finding the gain value, while with introducing MRAC controller the gain value is tuned adaptively as well as the adaptive controller gain can produce a smooth output.

4.0 CONCLUSION

The MRAC concept via stability approach has been used to tune the adaptive controller gain. Simple adaption law for controller parameter has been shown. The process under control is assumed by approximating to second order transfer function. The developed adaption rule has been applied and simulated. The obtained result from the simulation presents the effectiveness of the technique. The result performance can be enhanced by better choice of the length of the adaption period. The guaranteed nominal stability can be provided by using stability approach. As limitation of stability approach, the nominal system structure is assumed as second order transfer function. A very small time delay between command signal and the vehicle dynamic as in ideal vehicle resulting of this assumption.

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