International Journal of Research in Engineering and Science (IJRES)
ISSN (Online): 2320-9364, ISSN (Print): 2320-9356
www.ijres.org Volume 1 Issue 4 ǁ August 2013 ǁ PP.01-10

Controller Gain Tuning For Road Vehicle Convoy System Using Model Reference Adaptive Control Method

Aveen Uthman[1], Shahdan Sudin[2]
[1](*Faculty of Electrical Engineering/ UniversitiTeknologi Malaysia, Malaysia)*
[2](*Faculty of Electrical Engineering/ UniversitiTeknologi Malaysia, Malaysia)*

ABSTRACT: *In convoy system, the control system on each vehicle requires information about proceeding 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 found and simulated. This paper demonstrates the design process of an adaptive controller gain for a road vehicle convoy 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 convoy system with an adaptive gain controller is produced.*
Keywords - *two-vehicle look-ahead control strategy, model reference adaptive control, gradient approach.*

I. INTRODUCTION

Nowadays, problems related to traffic congestion is dressed 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 if 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.
Sensors are used to measure the speed and the position of the proceeding vehicle instead of estimating the information by the driver. The information which has been gotten by the sensor is used and processed by the following vehicle controller to produce the amount required speed and safe spacing distance.

In autonomous control approach, safe distance can be ensured automatically 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. [1,2]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.[1]

Figure1. Diagram of a road vehicle convoy system

II. 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 control the following vehicle 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[2]. 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[3] ,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[4] as shown in Fig. 2. A mathematical model for this control strategy is shown in Fig. 2 where irepresents 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 (kp) and damper constant (kv). 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).

$m\ddot{x}i = Kp_1 (x_{i-1} - x_i) + Kp_2 (x_{i-2} - xi) + kv_1(\dot{x}_{i-1} - \dot{x}_i) + Kv_2 (\dot{x}_{i-2} - \dot{x}_i)$(1)

Assuming unit mass for Eq. (1) and taking Laplacetransform, gives the following transfer function.$Xi = \frac{(k_{v1}s + K_{p1})x_{i-1} + (k_{v1}s + k_{p2})x_{i-2}}{S^2 + [k_{v1} + k_{v2})s + k_{p1} + k_{p2}}$ (2)

The transfer function in Eq. (2) depends on the followingspacing policy.

The aim of this strategy is to maintain string stability forlongitudinal motion within the vehicle following system orthe vehicle convoy, particularly between a vehicle with avehicle or between vehicles with a following vehicle. Thisstrategy is adopted in order to design a controller byinvestigating the following two policies

III. 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.[5]

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[3]. 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[3]. 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 [3] and[6] 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. 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. This can be done through radio communication or the rear vehicle having sensors to detect the above two parameters. Eq. (2) shown before is the transfer function for the fixed spacing policy.

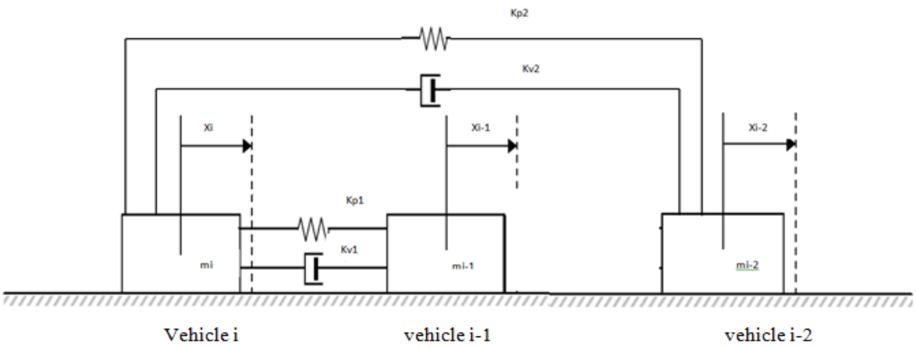

Figure 2. A mathematical model of a vehicle convoy system control strategy.

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 string stability 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.

The performance of the fixed headway spacing policy used in autonomous and cooperative vehicles following systems has been studied. 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$X_i=\frac{(k_{v1}s+K_{p1})x_{i-1}+(k_{v1}s+k_{p2})x_{i-2}}{S^2+[k_{v1}+k_{v2}+(k_{p1}+2k_{p2})h]s+k_{p1}+k_{p2}}$(3)

and the control law developed as:

$u_i=Kp_1(x_{i-1}-x_i-h\dot{x}_i)+Kp_2(x_{i-2}-x_i-2h\dot{x}_i)+kv_1(\dot{x}_{i-1}-\dot{x}_i)+Kv_2(\dot{x}_{i-2}-\dot{x}_i)$ (4)

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

$X_i=\frac{k_{v1}\left(s+\frac{K_{p1}}{k_{v1}}\right)x_{i-1}+k_{v2}\left(s+\frac{K_{p2}}{k_{v2}}\right)x_{i-2}}{S^2+(K_{p1}+2k_{p2})+k_{v1}\left(s+\frac{K_{p1}}{k_{v1}}\right)+k_{v2}\left(s+\frac{K_{p2}}{k_{v2}}\right)}$ (5)To simplify the control law and at the same time ensurestability, a pole-zero cancellation technique is chosen. Thiscan be achieved by introducing the constraint

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

This reduces equation (5) to

$X_i=\frac{k_{v1}x_{i-1}+k_{v2}x_{i-2}}{S+k_{v1}+k_{v2}}$(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).

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., [7]the actual vehicle acceleration is obtained after a certain time delay. This is given by the relation in equation (8).

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

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

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

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 strategyand vehicle dynamics is shown in fig.4 .

t is too small i.e. t~0 , then $s3 = 0$. The transfer function is thus reduced to a second order transfer function shown in equation (10).

By considering Kp1=kv1 and Kp2=Kv2

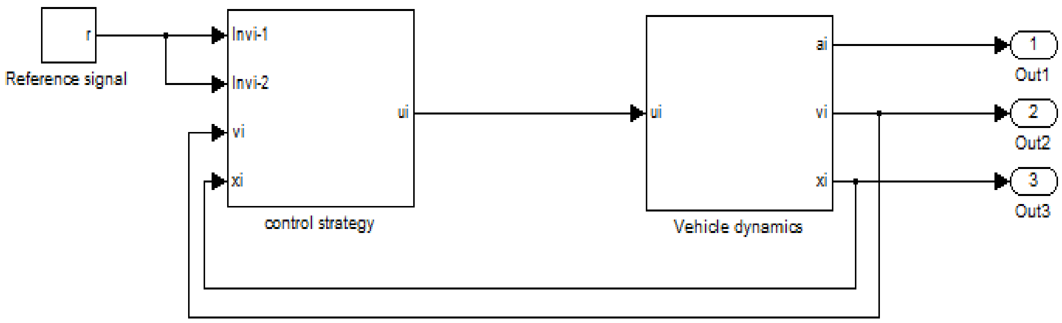

Figure 4. Block diagram consisting of the control strategy and vehicle dynamics

Eq. (10) is then simulated by using MATLAB Simulink. The controller block in Figure 4.6 contains two-vehicle look-ahead control strategy. The circuit is then simulated with the set values of *h*=1s with the values of *kp1* which is equal to kv1 set as 0.28, 0.34, and 0.42 respectively and Kp2 which is equal to Kv2 set 0.36,0.33 and 0.29 respectively .The results are shown in Figures 4.7 and 4.8,. There are some ripples or oscillations observed in the speed and acceleration plots. It is found that the values of *kp1*=0.28 and Kp2=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.

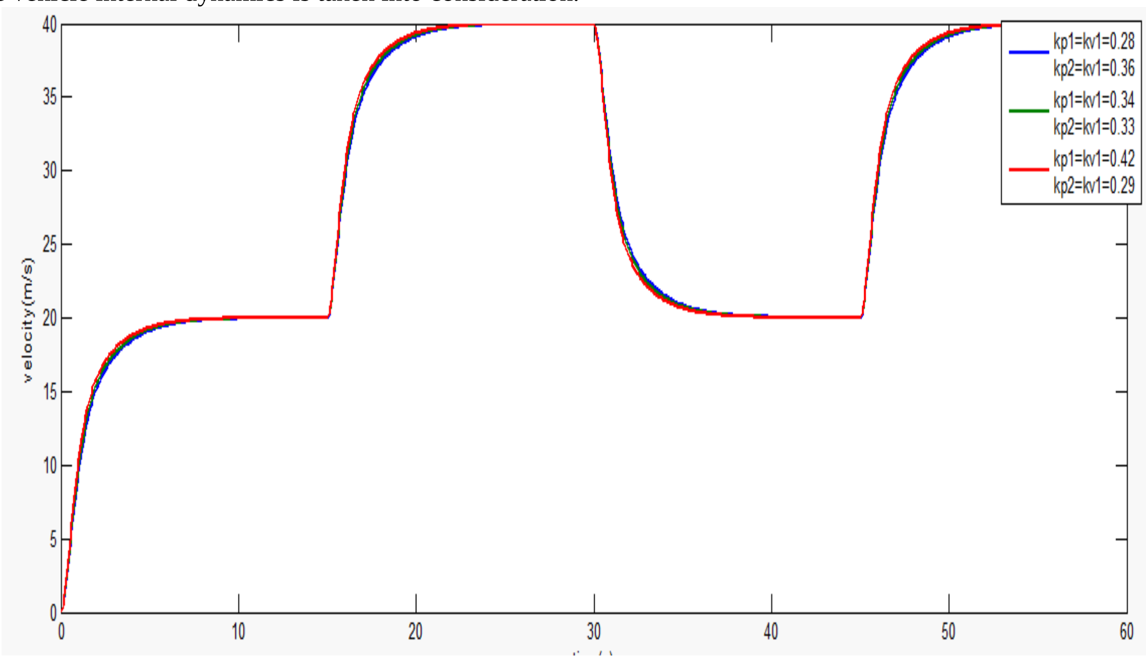

Figure 5. Speed response with fixed time headway for various *kp and kv*values and vehicle dynamics

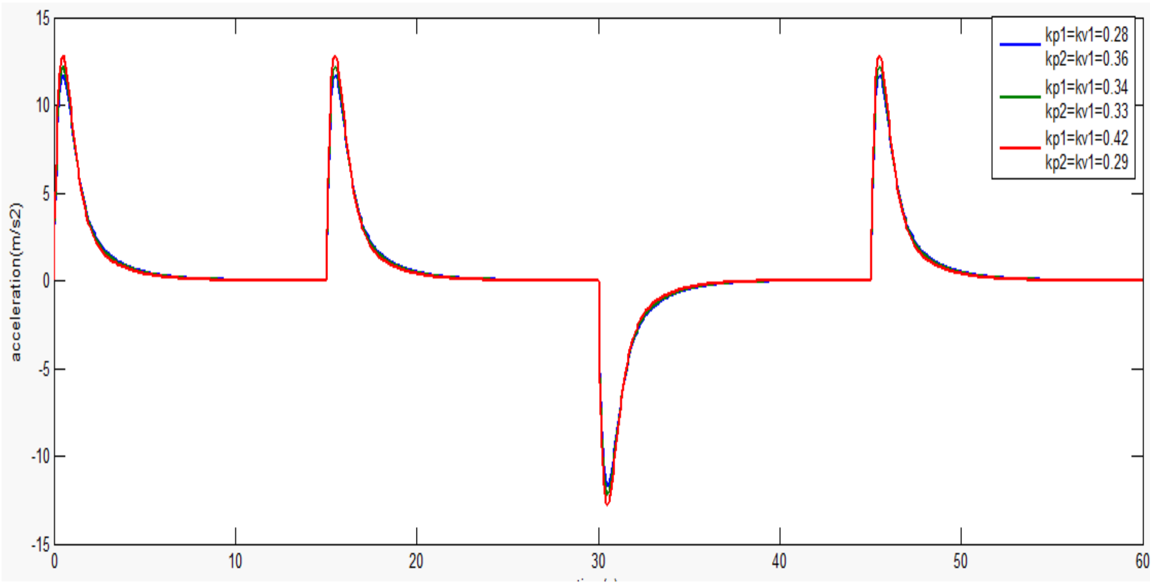

Figure 6. Acceleration response with fixed time headway for various *kp and kv*values and vehicle dynamics

IV. 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 5.1 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.

1. The Gradient Approach

The Gradient Approach of designing an MRAC controller is also known as the MIT Rule as it was first developed at the Massachusetts Institute of Technology (MIT), USA. This is the original approach developed for adaptive control design before other approaches were introduced to overcome some of its weaknesses. However, the Gradient approach is relatively simple and easy to use. In designing the MRAC controller, we would like the output of the closed-loop system (*y*) to follow the output of the reference model (*ym*). Therefore, we aim to minimize the error (*e*=*y*-*ym*) by designing a controller that has one or more adjustable parameters such that a certain cost function is minimized.

V. 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). This section presents a direct adaptive controller design which adapts the unknown vehicle parameters *kp1* and. *Kp2* The advantage of the adaptive approach is that unpredictable changes in the value of *kp1* and *kp2* can be easily accommodated. From the analysis of Figure 4.2 and Figure 4.3, kp1=kv1=0.28 and kp2=kv2=0.36 give the best response. So, it will be used in equation (10) to produce a reference model in equation (11) 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. (11).

$$x_i = \frac{0.28\,(S+1)x_{i-1} + 0.36(S+1)x_{i-2}}{s^2(\tau s+1) + 1.64s + 0.64} \quad (11)$$

The control objective is to adjust the controller parameters,kp1 and *Kp2*, so that *e(t)* is minimised. To do this, a cost function, *J (Θ)*is chosen and minimized. The cost function chosen is ofthe form

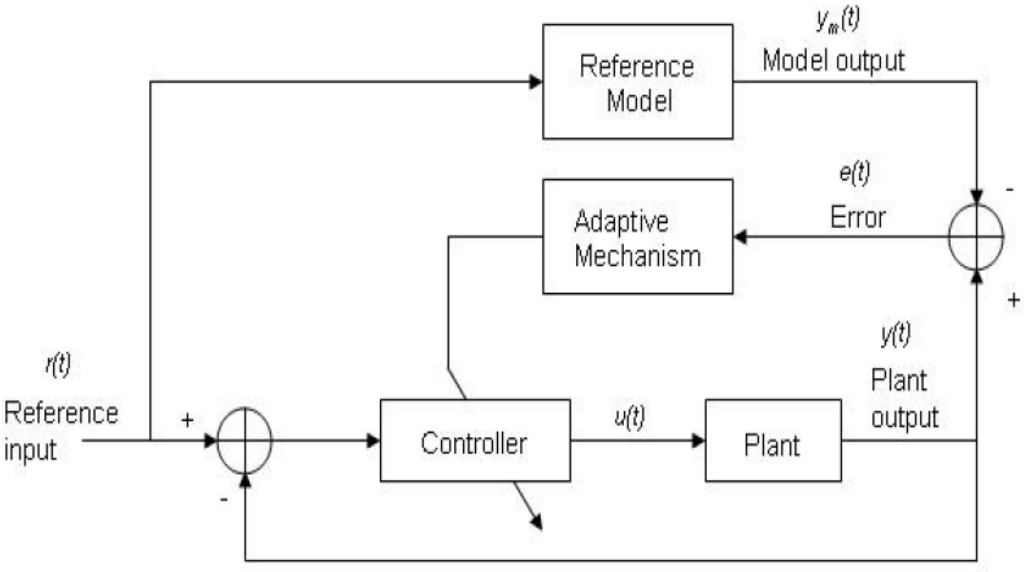

Figure 7 .General structure of an MRAC system

$y = \frac{\square 1(S+1)r1+\square 2\ (S+1)r2}{s^2+(2\square 1+3\square 2)s+(\square 1+\square 2)}$(12)

And the reference model is:

$y_m = \frac{0.28\ (s+1)r1+0.36(s+1)r2}{s^2+(1.64)s+(0.64)}$(13)

r(t) = Reference input signal
u(t) = Control signal
y(t) = Plant output
ym(t) = Reference model output
e(t) = Difference between plant and reference model output
= *y(t) - ym(t)*
e =y – ym

$e = \frac{\square 1(S+1)r1+\square 2\ (S+1)r2}{s^2+(2\square 1+3\square 2)s+(\square 1+\square 2)} - \frac{0.28(S+1)r1+0.36(S+1)r2}{s^2(\tau s+1)+1.64s+0.64}$

$$\frac{d\Theta 1}{dt} = -\gamma e\ \frac{(s+1)r1 - y(2s+1)}{s^2+(2\square 1+3\square 2)s+(\square 1+\square 2)}$$

$$\frac{d\Theta 2}{dt} = -\gamma e\ \frac{(s+1)r2 - y(3s+1)}{s^2+(2\square 1+3\square 2)s+(\square 1+\square 2)}$$

In this case we need to do some approximation: i.e. perfect model following, *y m=y* .Therefore, we then have,

$$\frac{d\Theta 1}{dt} = -\gamma e\ \frac{(s+1)r1 - y(2s+1)}{s^2+1.64s+0.64}$$

$\Theta 1 = -\frac{\gamma e}{s}\left[\frac{(s+1)r1 - y(2s+1)}{s^2+1.64s+0.64}\right]$

$= -\frac{\square e}{s}\left[\frac{r1}{s+0.64} - \frac{y(2s+1)}{s^2+1.64s+0.64}\right]$

and,

$\frac{d\Theta 2}{dt} = -\gamma e\ \frac{(s+1)r2 - y(3s+1)}{s^2+1.64s+0.64}$,

$\Theta 2 = -\frac{\gamma e}{s}\left[\frac{(s+1)r1 - y(3s+1)}{s^2+1.64s+0.64}\right]$

$= \left[\frac{r2}{s+0.64} - \frac{y(3s+1)}{s^2+1.64s+0.64}\right]$

As a result:

$kp1 = -\frac{\square e}{s}\left[\frac{r1}{s+0.64} - \frac{y(2s+1)}{s^2+1.64s+0.64}\right]$(14)

And,

$$kp2 = -\frac{\gamma e}{s}\left[\frac{r2}{s+0.64} - \frac{y(3s+1)}{s^2+1.64s+0.64}\right] \qquad (15)$$

Figure (8) shows the simulation block diagram of gradient approach adaptive control used for tuning of controller gains (kp1 and kp2).

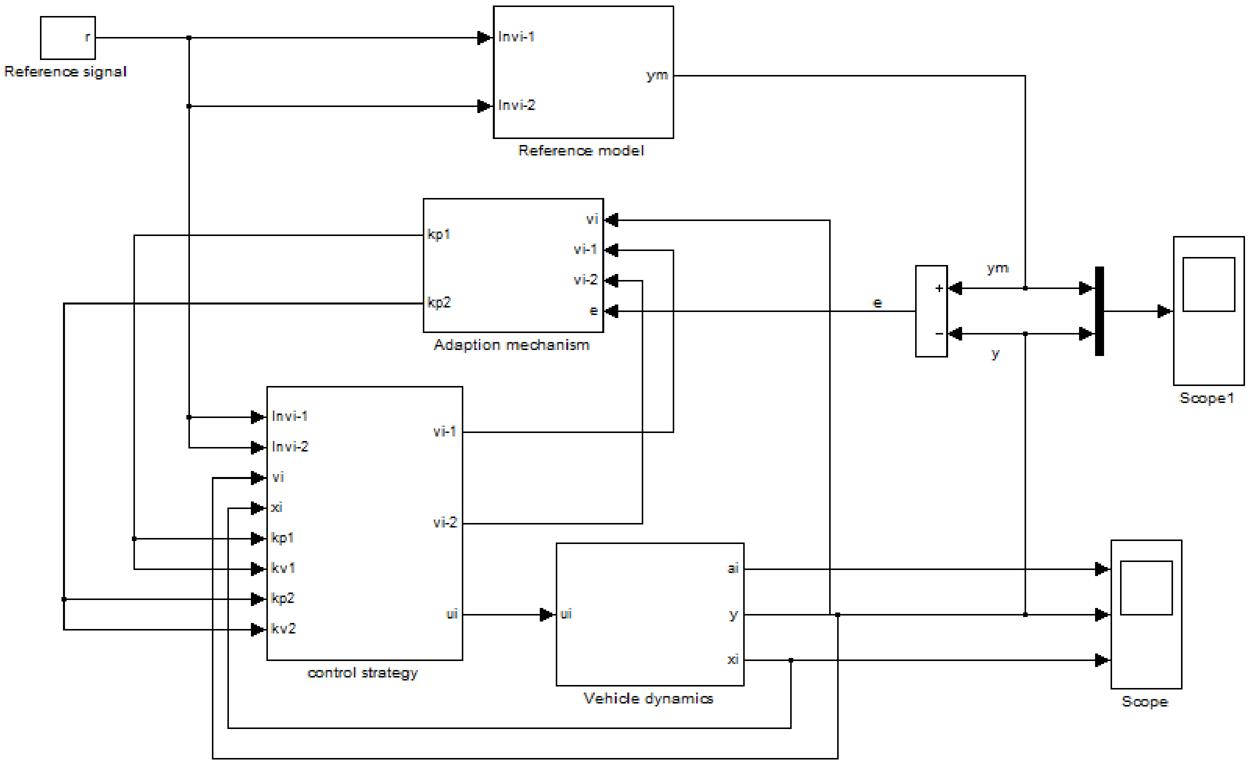

Figure 8.The gradient approach adaptive gain controller simulation diagram

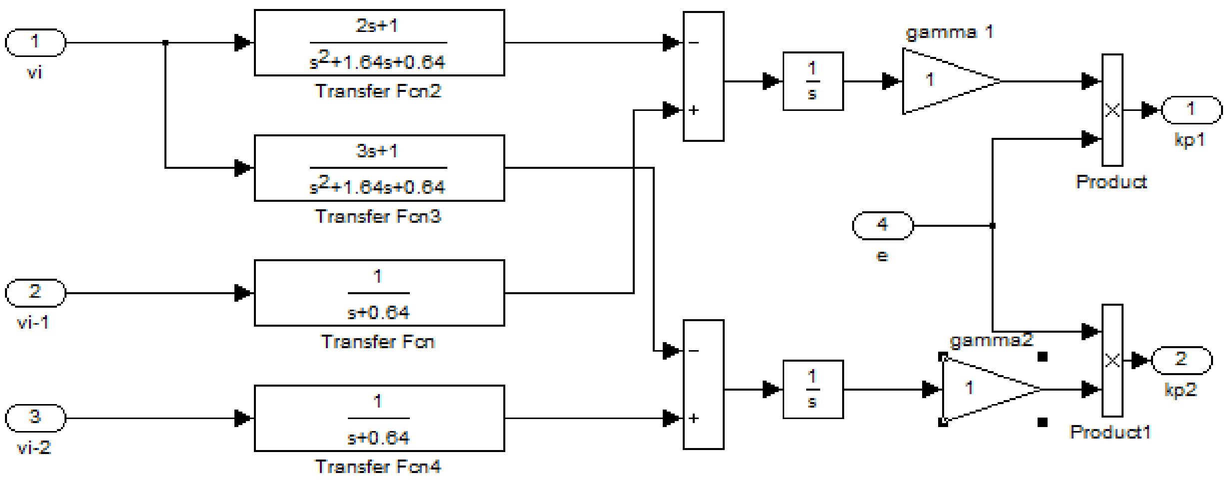

Figure 9. Simulation diagram of adaptive mechanism

The closed-loop system block diagram obtained is shown in Fig.8, where both γ in the equations are represented by gammas in simulation diagram. While fig.9 shows the adaptive mechanism simulation diagram.

VI. RESULTS AND DISCUSSION

The simulation of MRAC gradient approach adaptive controller gain design is then done again using MATLAB Simulink. Both the output of the system responses (y and ym) are shown in Fig. 10 and Fig. 11. Fig. 10 shows that the model is following the output perfectly with □ values of 0.1, while Fig. 11 on the other hand shows the acceleration response of y produces some ripples when there is no acceleration. It can be seen It can be considered that the system is a perfect model convoy system since that the output response for plant y perfectly follows the reference model ym. The adaptive controller gain is again simulated but this time with gamma.□values of 0.0001 meaning that decreasing gamma value until the ripple in acceleration is removed and this shown in fig. 12 and fig. 13.

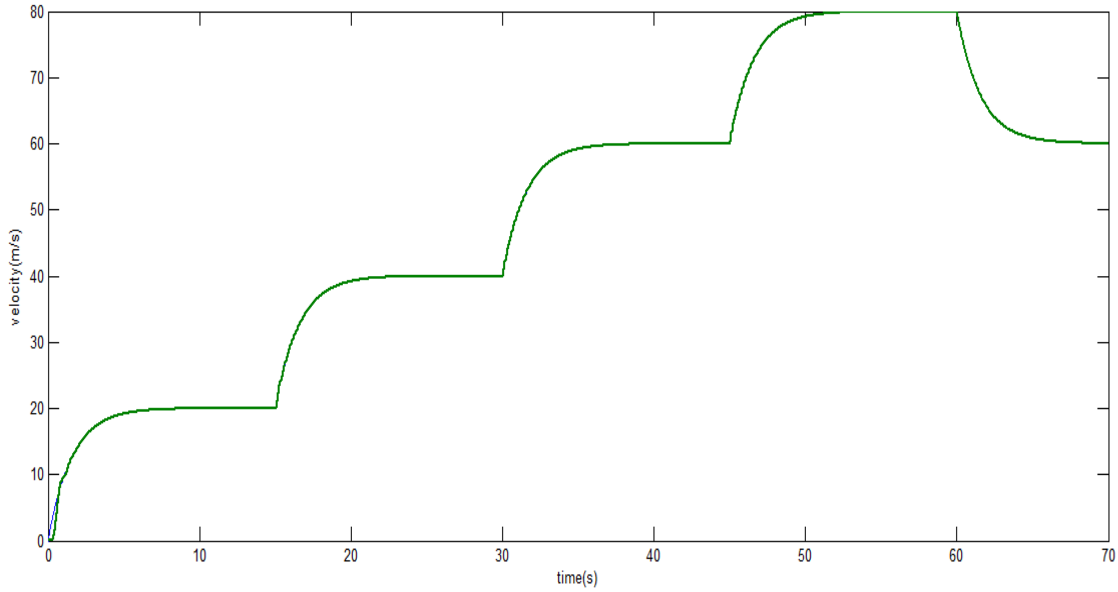

Figure 10. Comparison of y and ym for speed when □ is 0.1

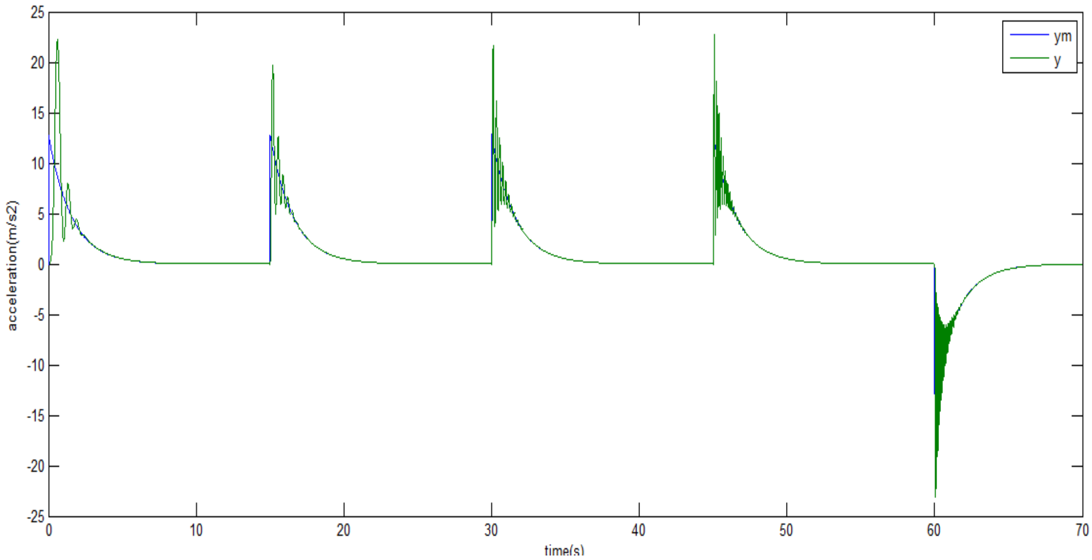

Figure 11. Comparison of y and ymfor acceleration when □ is 0.1

Fig. 12 shows that the model y is following the reference model ym closely with values of 0.0001 while fig. 13 shows that the model acceleration also follows the reference model acceleration but with some amount of delay.

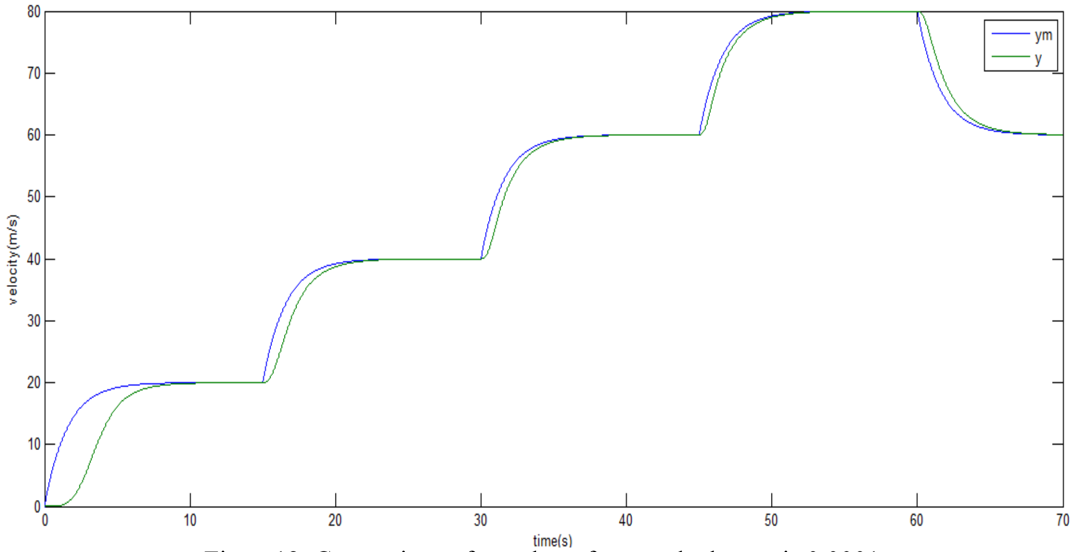

Figure12. Comparison of y and ym for speed when □ is 0.0001

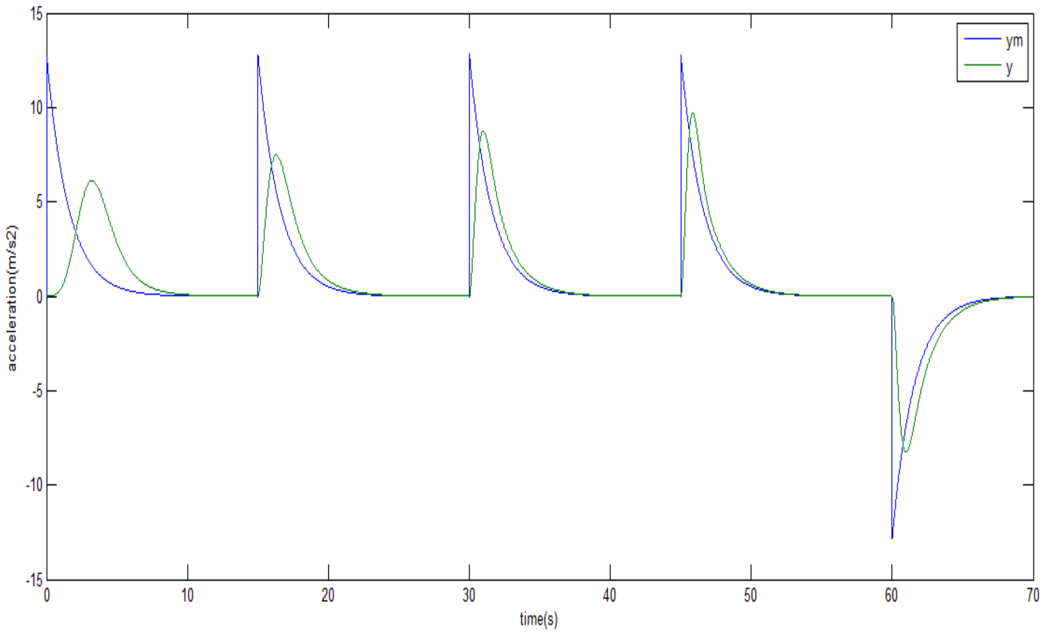

Figure 13. Comparison of y and ym for acceleration when □ is 0.0001

It can be said that better range of gamma values should be between 0.1 and 0.0001 in order to get acceptance simulation result.

As aresult, A two-vehicle look-ahead control strategy with fixed headway policy has been adopted to design a controller to produce an output, which can respond immediately to the change in input; in this case, the input is the speeds of two- vehicle look ahead with varying speed conditions. With normal controller, the response does not quite follow the input. With the introduction of the MRAC adaptive controller gain, the response can be made to follow the input when suitable reference model is chosen. Moreover, using MRAC adaptive controller gain produces a smooth output as compared to the other one.

VII. CONCLUSION

The adaptive controller gain tuning for two-vehicle look –ahead convoy system has been investigated using Model Reference Adaptive Control concepts and the gradient approach. Simple adaptation law for the controller parameters has been presented assuming that the process under control can be approximated by a second order transfer function. The developed adaptation rule has been applied and simulated. The obtained results show the effectiveness of the technique. The resulting performance could be improved by a better choice of the length of the adaptation period and better choice of adaption gain gamma.Although of gradient approach is easy to apply but it also known to have some disadvantages; the speed of adaptation depends on the values of the command signal. This problem is often dealt with by using a normalized adaptation rule. Second, the gradient approach does not guarantee the stability of the nominal system. The Lyapunov approach can be used to provide guaranteed nominal stability. A further limitation of the approach is the assumption of a structure for the nominal system. In this paper, a second order transfer function has been assumed resulting from the assumption of a very small time delay between the command signal and the vehicle dynamics as in ideal vehicle. Further investigation on the comparison with other control strategies will be done in future papers.

VIII. Acknowledgements

The authors would like to acknowledge their gratitude toFaculty of Electrical Engineering, Universiti Teknologi Malaysia for providing the resources and support in the completion of this paper.

REFERENCES

[1] Ng, T.C., J.I. Guzman, and M.D. Adams. *Autonomous vehicle-following systems: A virtual trailer link model*. in *Intelligent Robots and Systems, 2005.(IROS 2005). 2005 IEEE/RSJ International Conference on*. 2005: IEEE.

[2] Cerone, V. and D. Regruto, *Bounding the parameters of linear systems with input backlash.* Automatic Control, IEEE Transactions on, 2007. **52**(3): p. 531-536.

[3] Sudin, M.R.S., Shahdan, and M. Sapiee, *Road Vehicle Following System With Adaptive Controller Gain Using Model Reference Adaptive Control Method.* 2009.

[4] Cook, S.S.a.P.A., *Dynamics of Convoy Control Systems with Two-Vehicle Look-Ahead Strategy*. International Conference on Robotics, Vision, Information and Signal Processing, 2003. **pp. 327-332.**

[5] Yanakiev, D. and I. Kanellakopoulos. *A simplified framework for string stability analysis in AHS*. in *Proceedings of the 13th IFAC World Congress*. 1996.

[6] Sudin, S., *Dynamics And Control Of Vehicle Convoy System.* PhD Thesis.School of Electrical and Electronic Engineering, Faculty of Engineering and Physical Sciences, The University of Manchester., 2005.

[7] Darbha, S. and K.R. Rajagopal, *Intelligent cruise control systems and traffic flow stability.* Transportation Research Part C: Emerging Technologies, 1999. **7**(6): p. 329-352.

[8] Shladover, S.E., *Longitudinal control of automated guideway transit vehicles within platoons.* Journal of Dynamic Systems, Measurement and Control, vol. 100 no. 4, 1978.

[9] Sudin, S. and P.A. Cook. *Two-vehicle look-ahead convoy control systems*. in *Vehicular Technology Conference, 2004. VTC 2004-Spring. 2004 IEEE 59th*. 2004: IEEE.

Aveen Uthman she obtained her bachelor's degrees in Mechatronics engineering from Baghdad

University, Iraq in 2007.She is currently master student of Mechatronics and Automatic Control Engineering program at Faculty of Electrical Engineering, Universiti Teknologi Malaysia (UTM), Skudai, Johor, Malaysia. She is a member staff in control lab. at Sulaimani Technical College, Kurdistan Region, Iraq

Shahdan Sudin is a senior lecturer in the Department Control and Mechatronics Engineering, Faculty of

Electrical Engineering, Universiti Teknologi Malaysia, Skudai Johor.He received his M.Sc.E.E.in control and optimization from UTM in 1994 and PHD from the University of Manchester, United Kingdom in 2005. He has more than13 years experiences in the field of his proposed project (Dynamics and Control of Chapter 1 Vehicle Convoy Systems). His research interest includes control and optimization especially dynamic and control of vehicle convoy system and the stability of vehicle/following system as well.