Internet of Vehicle for Two-Vehicle Look-Ahead Convoy System Using State Feedback Control

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Abstract In recent years, the success of the Internet of Things has been extended into the field of transportation making it possible to have the internet of Vehicle (IoV). The combination of IoV and machine learning is expected to provide a robust system for high mobility vehicles that exhibit strong dynamics in the wireless channels, network topologies and traffic dynamics. We examine the use of IoV for two-vehicle look-ahead convoy in addressing the problem of safety and comfort in a two-vehicle convoy system. The two-vehicle look-ahead convoy systems have been getting much attention by researchers due to its inherent problem of string-instability, passengers' discomfort and its involvement in many areas of applications, which include the public and defence sectors. In this chapter, the dynamics model of the convoy was formed using the simplified vehicle model. The conventional control strategy was adopted to control the convoy. The best response of the controlled vehicle was achieved with the design parameters of 0.28 for kp1 and kv1, and 0.36 for kp2 and kv2,

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respectively. An improvement was made in the controller design through the design and implementation of a state-feedback controller (SFC) using the pole placement technique. The performance of the two controllers was evaluated with respect to the controlled vehicle's speed, acceleration and jerk. It was clearly seen in the presented result that the SFC controller gave a perfect speed tracking of the controlled vehicle without any overshoot. An acceptable acceleration of 2 ms^{-2} was achieved with zero value of jerk in the controlled vehicle. This signifies string-stability, achievement of acceptable acceleration and passengers' comfort in the controlling vehicle using the proposed SFC.

Keywords Acceleration · Connected cars · Internet of Vehicle · State-feedback controller · Vehicle-to-Vehicle · Vehicle convoy

1 Introduction

The advancement in information communication technology has paved way for connected cars known as the internet of vehicles (IoV). The IoV is defined as the exchange information between the vehicle and its environment through different communication media [1]. The IoV allows for vehicles to communicate with human drivers, other vehicles, road infrastructures, road users and provide several services such as the fleet management systems in real-time [2]. The ability to exchange such useful information is changing the way vehicle operates and making it possible to have intelligent transport systems and co-operative intelligent transport systems [3].

The communication is achieved via distributed networks or vehicular ad hoc networks (VANETs). The VANET is a mobile ad hoc network in which nodes (vehicle) are clustered based on correlated spatial distribution and relative velocity using clustering algorithms [4]. These vehicles are incorporated with wireless transceivers that allows to communicate with their environment via the internet or line of sight communication technologies. There are different types of IoV network communication. They include Intra-Vehicle [5], Vehicle-to-Vehicle (V2V) [6], Vehicle-to-Infrastructure (V2I) [7], Vehicle-to-Cloud (V2C), and Vehicle-to-Pedestrian (V2P) [8]. While the V2V involves exchange of information between automobiles the other forms of communication involve the exchange of information between the vehicle and its surroundings.

The V2V network enables vehicles to exchange information such as speed, position of surrounding vehicles, direction of travel, acceleration, braking and loss of stability [1]. Such information can be used to increase the safety by providing different level of services to vehicle such as warning, brake or steering control. The use of IoV has been proposed to reduce collision and maintain stability of moving vehicles at the roundabout in [9].

In this research work, we focus on the use of V2V to solve the problems of safety and comfort of passengers in a two-vehicle convoy system. This is because the scope of work is limited to exchange of information between automobiles. Two-vehicle convoy system is a configuration of vehicles in a convoy in such a manner whereby the control vehicle is using the information (spacing, speed, and acceleration) of the neighboring (two ahead) vehicles. The two vehicles ahead are called the predecessor and lead vehicles where the spring and damper techniques have been utilized. One of the two control policies (constant inter-vehicular spacing or variable inter-vehicular spacing) need to be adopted for safety. Musa et al. [10] used the concept of spring-mass-damper system to present an idea of vehicle convoys' topology using the control policy of variable time-headway.

String stability is the most significant aspect that needs to be consider in such convoy's configuration to achieve stable movement. The term string stability is the ability of the vehicles in a convoy to move without amplifying the oscillation of the convoy leader off string. The convoy system is said to be stable if the oscillation of the lead-vehicle dies as it propagates along the convoys' stream [11]. Finally, the passenger's comfort should also not to be compromise. Passengers comfort can be determined by the jerk of the controlled vehicle, which is the third derivative of the control vehicles displacement. To achieve this, the control vehicle needs the speed, spacing and acceleration of the neighboring vehicles. This information is exchanged between the vehicles involved in the convoy using two types of communication technologies which are the dedicated short-range communications (DSRC) and the 5GLTE cellular technology. There are challenges associated with the reliability of the 5GLTE wireless communication in high mobility networks. The application of machine learning and deep learning can be used to address some of the challenges such as complexity in channel estimation, allocation of resources and network topology.

In this chapter we present the concept of V2V communication and the State-Feedback Controller (SFC) to achieve the safety and comfort in a two-vehicle convoy system. The V2V would allow the exchange of information between the controlled vehicle and the neighboring vehicle. The State-Feedback Controller (SFC) would be used via the pole-zeros approach to control the movement of the controlled vehicle to achieve the desire parameters.

The rest of this chapter is structured as follows. Section 2 covers the system architecture of the of IoV and V2V application. Sections 3 and 4 explains the mathematical modeling of the proposed two look-ahead vehicle convoy and vehicle dynamic, respectively. Section 5 presents the results obtained and discussion. Section 6 provides the conclusion and further work.

2 System Architecture

In this section, we discuss the various components of the IoV and the architecture of the two-vehicle look-ahead convoy.

2.1 IoV Components

The internet of things consists of four major components which (1) IoT devices; (2) communication technology; (3) Internet; and (4) data storage and processing [12]. Similar to the IoT, the IoV consist of four major components. One is the node in this case the vehicle becomes the node. The second is the communication technology. The third is the internet that allows for remote connection between the vehicle and environment and finally the fourth is the data storage and processing for control management and intelligent services. The illustration of the IoV (V2V) is shown in Fig. 1.

The four components are described as follows.

The Node. This consist of sensors and actuators for sensing and control of the vehicle via the On-board Unit (OBU) and user interfaces. The sensors help to detect events, driving patterns and environmental situations. The OBU are designed to have various all kinds of interconnectivity for transmission of information between the vehicle and other entities. The user interface can be either auditive, visual or haptic. The user interfaces provide useful application and services to the drivers and passengers such as timely notifications of lane changes, emergency braking, traffic situations and avoidable obstacles or head on collisions.

The Communication Technology. There are various communication technologies that have been designed to support vehicular communications. Some of the technology's supports are either short-range or long-range communication. The two

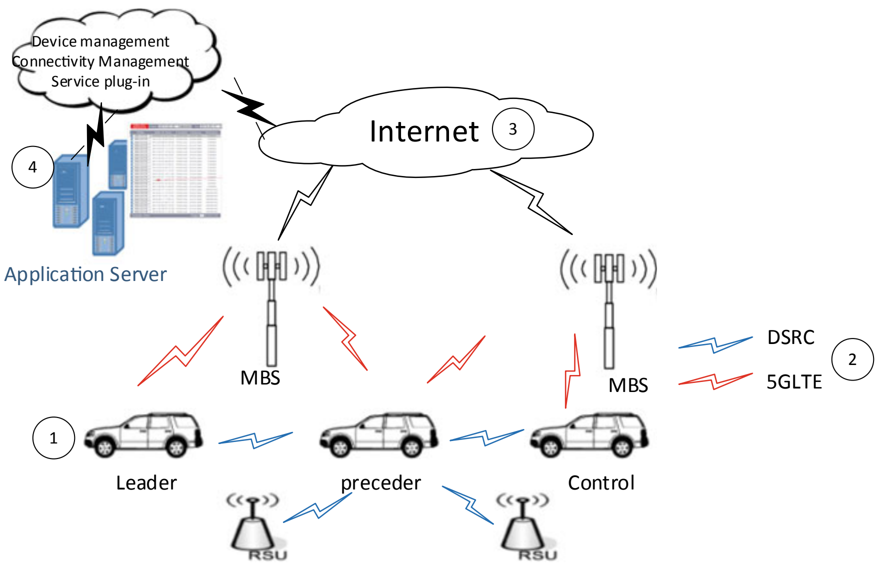


Fig. 1 Internet of Vehicle for V2V two-vehicle look-ahead convoy

major communication technologies for V2V communication. One is the dedicated short-range communications (DSRC) [13] and the second is the 5GLTE cellular technology. The DSRC is an established technology for V2V and operates in 75 MHz of spectrum (5.85–5.925) GHz. It supports a transmission range of 300 m and a latency of 25 ms. The 5GLTE is expected to deliver 1 ms latency and operate at cellular frequency with much wider bandwidth, better penetration and lesser interference [14]. Other forms of communication technology include the GSM, Wi-FI, and Bluetooth.

The Internet. The internet is a platform where paths are provided to carry and exchange data and network information between multiple subnetworks [12]. The connection of IoT devices to the Internet enables data to be available anywhere and anytime provided there is adequate security both at the network and physical level. Several network protocols have been designed to handle network communication for IoV both at the physical and network layer. Some of the protocols are IEEE 802.11p directional medium access control (DMAC) and vehicular cooperative media access control.

The Data Storage and Processing. This include the data acquisition, transmission, storage and computing of big data that is transferred for automotive telematics, autonomous vehicles and the dynamic traffic monitoring among many others. It also include statistical and artificial intelligence tools for processing of data needed for decision making in different scenarios such as traffic congestion, dangerous road conditions, lane and convoy coordination. The machine learning and deep leaning are subset of artificial intelligence needed in high mobility networks that exhibit strong dynamics in the areas such as wireless channels, network topologies and traffic. They enable machines to learn from large amounts of data in order to perform certain task without explicitly programming it. The challenge of complexity in channel estimation, resource allocation, link scheduling and routing for the vehicular communication in 5GLTE can be handled using the Artificial intelligence.

2.2 IoV Architecture for Two-Vehicle Look-Ahead Convoy

In this section we describe the operation of the two-vehicle look-ahead convoy using IoV five-layer architecture. The IoV is expected to enhance the exchange of information of the dynamics of the individual vehicles involved in the convoy. This information is sent to the controllers in the vehicles. The IoV architecture consists of five layers. We describe the five layers as follows.

The First Layer. The first layer is the data acquisition layer. This consist of sensors and actuators for sensing and control of the vehicle via the On-board Unit (OBU). The OBU is equipped with multiple wireless communication interface. This enables the vehicle to exchange information with other vehicles, the RSU and the internet. Data acquisition of the speed and position are obtained from the vehicle via inbuilt

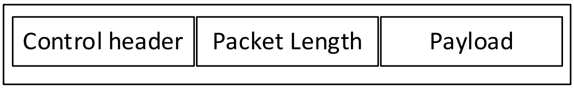


Fig. 2 Packet structure

sensors. This data can be compressed into a packet as shown in Fig. 2. The control header consists of the control field for communication, the packet length hold length of the packet and the payload contains the data being sent.

The packets are sent with unique ID for each vehicle to the controlled vehicle. The OBU receives the packet and the data is sent to the state feedback controller (SFC). Based on the information, the SFC can adjust the movement of the controlled vehicle using the model described in Sect. 3.

The Second Layer. The second layer is the communication technology. It consists of the radio frequency technology required for communication between the OBU and the roadside unit (RSU) or mobile base station (MBS) required for the 5GLTE. It is assumed that all vehicles are connected to the network using the 5GLTE technology at the same time the vehicles can communicate with the RSU using the DSRC.

The Third Layer. The third layer is the edge network. It handles the distributed intelligence and fog computing needed for the V2V communication. Traffic efficiency and safety servers are installed in the edge network in order to reduce amount of load in terms of data for the core network and the reduce latency time.

The Fourth Layer. The fourth layer is the core network. The core network handles the security, multicast, IP routing and the mobile packet core needed for the V2V communication. It also coordinates communication between the edge networks.

The Fifth Layer. The last layer is the Data center and cloud. This layer handles the data processing and application layers. The information of each vehicle can be stored in the cloud. Also, the function of the SFC can be computed in the cloud and sent to the controlled vehicle. Figure 3 shows the IoV architecture for Internet of Vehicle.

2.3 Platform Used for Implementation of the Model

The MATLAB platform was utilized in which the Similink blocks were used to model the mathematical equation that represents the behavior of the single vehicle. Simplified vehicle dynamics was used to represent the single vehicle system. The modeled single vehicle was cascaded to form the topology of the two-vehicle look-ahead using the bases of the mass-spring damper as shown in Fig. 4. The real time three dimension (3D) visualization of the topology behavior was translated using MapleSim 2019. MapleSim is object oriented software, which permits the modeling of complex model within fraction of minutes. The MapleSim platform provides a simple and flexible ways to model and visualized the true behavior of the model at a glance. It also allowed instant changes of the model parameters and the effect

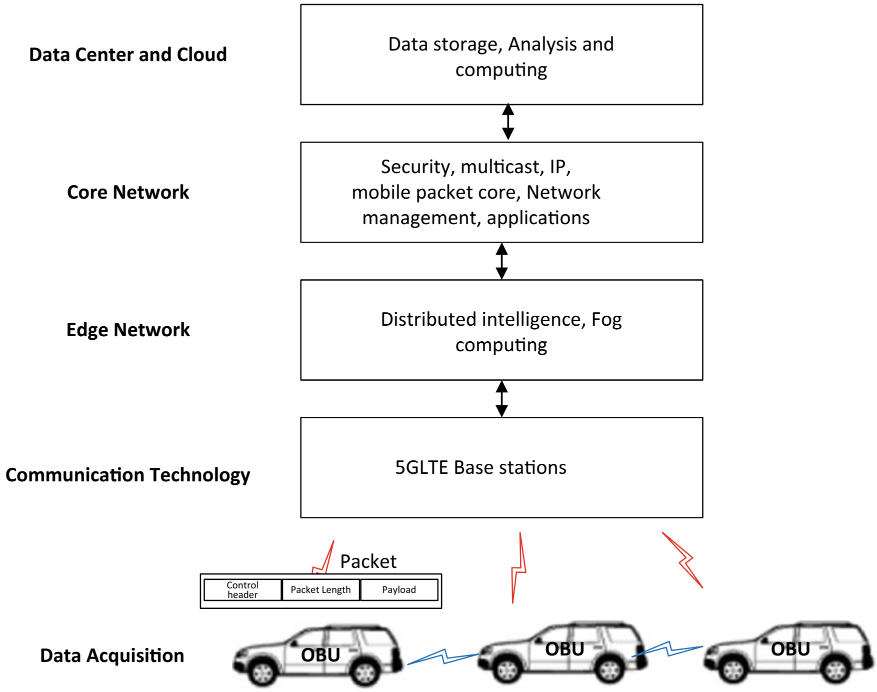


Fig. 3 IoV architecture for Internet of Vehicle

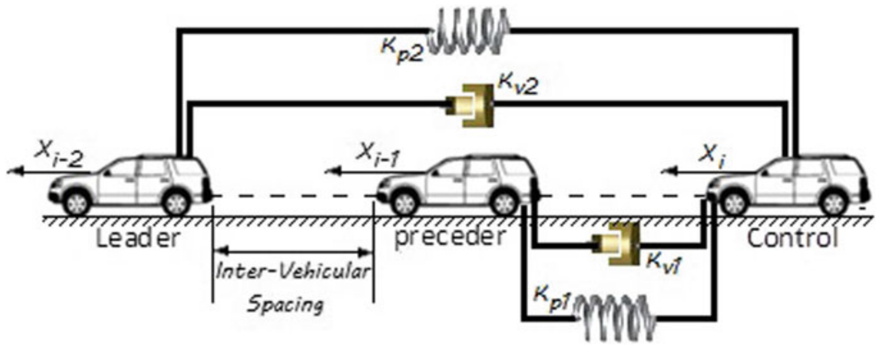


Fig. 4 A Conventional two-vehicle look-ahead topology

of the changes will immediately show on the graphical simulation and on the 3D visualization.

3 Modeling of the Two Look-Ahead Vehicle Convoy Strategy

In this section, the concept of the two-vehicle convoy system would be developed from the 2nd Newton's law and expressed using the mass-spring-damper as shown in Fig. 4 starting from the basics as.

Where, x_i, x_{i-1} and x_{i-2} are the positions of the controlling vehicle, preceding and lead vehicle respectively.

$$m\dot{x}_i = \sum_{n=1}^{2} \{kp_n(x_{i-n} - x_i) + kv_n(\dot{x}_{i-n} + \dot{x}_i)\} \tag{1}$$

Equation (1) gave the spring-damper-representation of the two-vehicle look-ahead model. Where by m represents the mass of the vehicle in kg, k_p is the spring constant, kv is the damper constant, derivative of x_i and derivative of x_{i-n} when n stands for 1 and 2 and are the speed of the controlled, predecessor and lead vehicle respectively. Taking the Laplace transformation of Eq. (1) at unit mass yield Eq. (2):

$$X_i = \frac{\sum_{n=1}^{2} \{(kp_n s + kv_n)X_{i-n}\}}{s\left(s + \sum_{n=1}^{2} kv_n\right) + \sum_{n=1}^{2} kp_n} \tag{2}$$

The transfer function in Eq. (2) depends on the vehicle following spacing policy adopted. Spacing policy is a predefine rule, which enable the controlled vehicle to regulate it distance with respect to the neighboring vehicles in the convoy. Controller should be implemented to regulate the vehicle speed according to the designed spacing policy [15, 16]. The time headway policy is used in this chapter it varies according to the speed of the neighboring vehicles. To achieve such spacing regulation, the time headway is introduced to Eq. (2) as:

$$X_i = \frac{\sum_{n=1}^{2} \{(kp_n s + kv_n)X_{i-n}\}}{s^2 + s\left\{\sum_{n=1}^{2} kv_n + h(kp_1 + 2kp_2)\right\} + \sum_{n=1}^{2} kp_n} \tag{3}$$

For stability to occur the pole-zero cancellation is utilized by introducing the constraints Eq. (4) [17]:

$$\frac{kp_1}{kv_1} = \frac{kp_2}{kv_2} = (kp_1 + 2kp_2)h \tag{4}$$

Under the constraints in Eq. (4), Equation (3) can now be reduce to single pole, which will lead to string stable convoy as achieved in Eq. (5):

$$X_i = \frac{\sum_{n=1}^{2} kv_n \cdot x_{i-n}}{s + \sum_{n=1}^{2} kv_n} \tag{5}$$

The control signal u_i is directly proportional to the applied force f on the vehicle, which was modelled as initial mass [15–18] as shown in Eq. (6).

$$\ddot{x}_i = f(\dot{x}_i, u_i) \tag{6}$$

Hence the control signal can be represented by (7):

$$\ddot{x}_i = u_i \tag{7}$$

where $\ddot{x}_i$ is the acceleration of the controlled vehicle. The control signal can be obtained from Eq. (3) as:

$$u_i = \sum_{n=1}^{2} kp_n(x_{i-n} - x_i - nh\dot{x}_i) + \sum_{n=1}^{2} kv_n(\dot{x}_{i-n} + \dot{x}_i) \tag{8}$$

4 Vehicle Dynamic

The vehicle internal dynamics only is considered in the model for simplicity. The simplified vehicle model used a lag function to represent the model. The concept of the lag function comes to existence since the actual vehicle's acceleration can only be obtained after certain time delay τ as in Eq. (9):

$$\tau\dot{x} + \ddot{x} = u \tag{9}$$

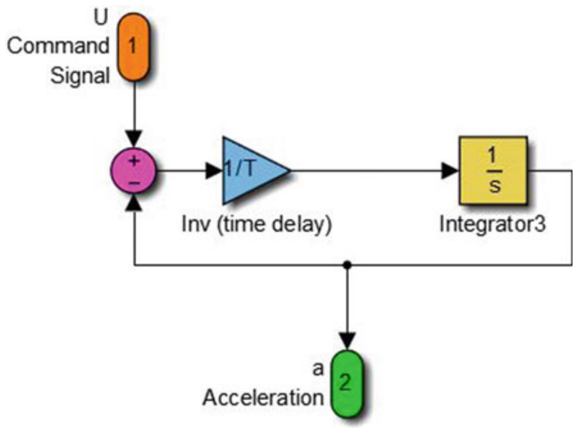
Now the time delay can be included in the convoy vehicle model of Eq. (3) as shown:

$$X_i = \frac{\sum_{n=1}^{2} (kp_n s + kv_n)x_{i-n} + \left(2\mathrm{s} + \mathrm{kp}_2\right)x_{i-n}}{s^2(\tau s + 1) + \left\{\left(\sum_{n=1}^{2} kv_n + \sum_{n=1}^{2} nkp_n\right)h\right\}s + \sum_{n=1}^{2} kp_n} \tag{10}$$

With the introduction of the vehicle dynamics in Eq. (10) the command signal produced will now be used to drive the vehicle dynamic as shown in Fig. 5.

Taking the value of $\tau = 1$ (delay) and $h = 1\mathrm{s}$ (headway) the best acceptable acceleration of 2 ms^{-2} [10] is achieved when $kp_1 = kv_1 = 0.28$ and $kp_2 = kv_2 = 0.36$ from the transfer function as:

Fig. 5 Simplified vehicle dynamic



$$X_i = \frac{(s+1)(0.28x_{i-1} + 0.36x_{i-2})}{s^3 + s^2 + 1.64s + 0.64} \tag{11}$$

Certain trail an error where carried out with different values of spring and damper constants to come up with the best values of, *kp*'s and *kv*'s which can be justified from Figs. 6 to 7.

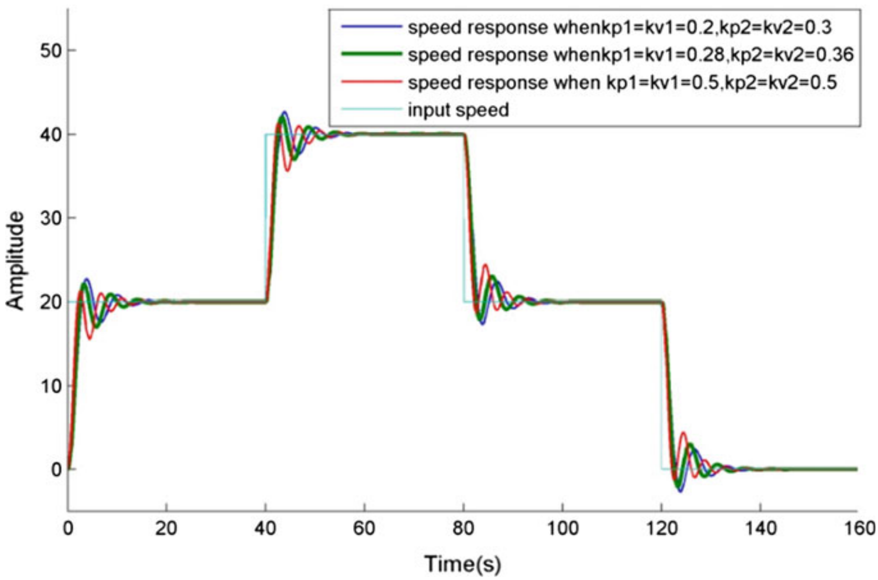


Fig. 6 Speed responses with different constants (*kp*'s and *kv*'s) values

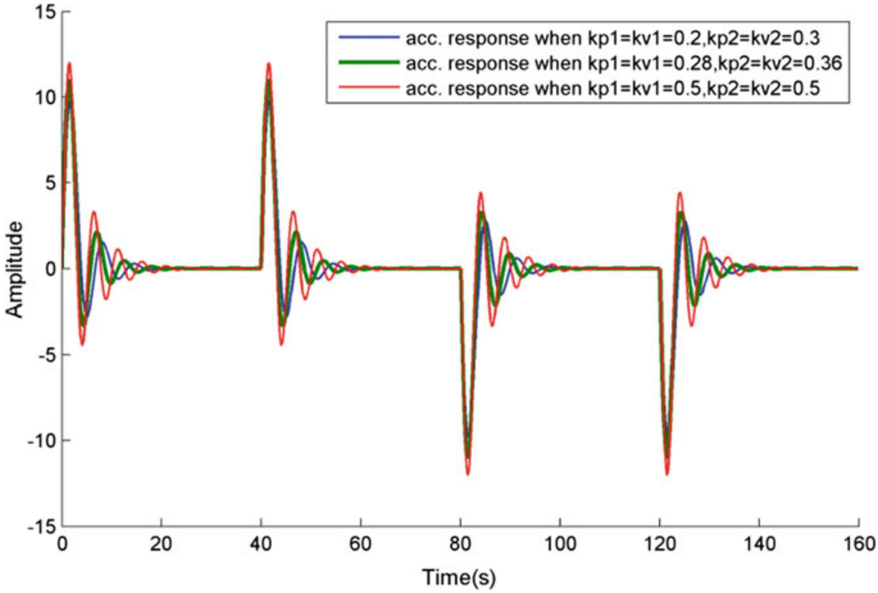


Fig. 7 Acceleration response with different constants (k_p's and k_v's) values

The best spring's and damper's gain selection can be seen in Fig. 6 using trial an error. Several gains are applied through tuning and the gain that gives the best performance was adopted throughout the convoy's model.

Figure 7 shows acceleration response using different gains, the selected gain values gave smooth, acceptable and low acceleration values of less than 2 ms^{-2}. The low the acceleration the low the jerk. Hence, the more the passenger's comfort.

4.1 SFC Design Using Pole-Placement Approach

The SFC was designed using the pole-placement approach to enable the transfer of all the poles of closed-loop independent to each other [19].

Pole Placement Topology

The state space equation for the plant can general be represented as:

$$\left.\begin{aligned} \dot{x} &= Ax + Bu \\ y &= Cx + Du \end{aligned}\right\} \tag{12}$$

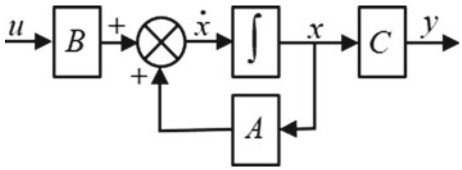


Fig. 8 Plant state-space

where A is the state transition matrix, B is the input matrix, C is the output matrix, x is the state vector, y is the output and $\dot{x}$ is the input. The state-space map graph is as shown in Fig. 8

In order to achieve the close-loop pole values from the plant state-variable feedback as shown in Fig. 9 the gain need to be adjusted to a suitable value.

Hence Eq. (12) can now be represented as:

$$\dot{x} = Ax + B(-kx + r) \tag{13}$$

In order to design a SFC with pole placement method, the state-space representation of the plant should be developed. In this chapter, the system transfer function is converted to state-space equation as illustrated in [10]. The plant representation in term of input and output is given as in Fig. 10.

Based on the transfer function Eq. (11) of the plant model, the following assumptions are made which resulted to Fig. 11:

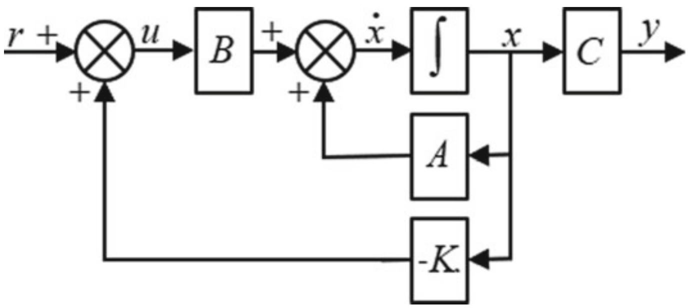
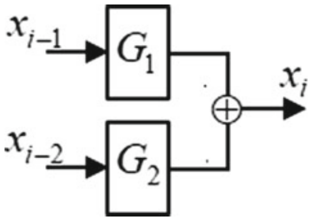


Fig. 9 Plant state-variable feedback

Fig. 10 Block diagram of the Plant state-variable feedback for the propose convoy



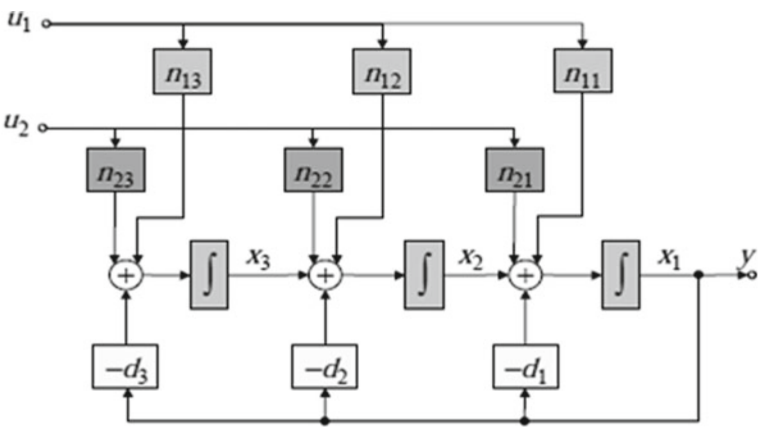


Fig. 11 Block diagram of the state variables, inputs, and output

$$x_{i-1} = u_1 \tag{14}$$

$$x_{i-2} = u_2 \tag{15}$$

Figure 10 is a Multi Input Single Output (MISO) system, therefore:

$$G(s) = \begin{bmatrix} G_1 & G_2 \end{bmatrix} \tag{16}$$

and

$$G(s) = \begin{bmatrix} \frac{b_1(s)}{a_1(s)} & \frac{b_m(s)}{a_m(s)} \end{bmatrix} \tag{17}$$

where $G(s)$ can also be express as:

$$G(s) = \frac{[n_1(s) \ldots n_m]}{d(s)} \tag{18}$$

$$G(s) = \frac{\left[n_{11}s^{n-1} + n_{12}s^{n-2} + \cdots + n_{1n} \cdots n_{m1}s^{n-1} + n_{m2}s^{n-2} + \cdots + n_{mn}\right]}{s^n + d_1 s^{n-1} + \cdots + d_n} \tag{19}$$

The numerator polynomial is defined as (20):

$$n_1(\mathrm{s}) = \frac{b_1(s)\mathrm{d}(\mathrm{s})}{a_1(\mathrm{s})} \tag{20}$$

The inputs and the output variables can be represented by Fig. 10.

In general, the MISO canonical form matrix is shown as Eqs. (21)–(22):

$$A = \begin{bmatrix} -d1 & 1\ 0 \cdots 0 \\ -d2 & 0\ 1 \cdots 0 \\ \vdots & \vdots\ \vdots \ddots \vdots \\ -d_{n-1} & 0\ 0 \cdots 1 \\ -dn & 0\ 0\ \ 0\ \ 0 \end{bmatrix} \tag{21}$$

$$B = \begin{bmatrix} b_{11} & \cdots & b_{n-1} \\ b_{12} & \cdots & b_{n-2} \\ \vdots & \ddots & \vdots \\ b_{1(n-1)} & \cdots & b_{m(n-1)} \\ b_{1n} & \cdots & b_{mn} \end{bmatrix} \begin{bmatrix} u_1 \\ \vdots \\ u_m \end{bmatrix} \tag{22}$$

$$\mathrm{C} = \begin{bmatrix} 1 & 0 & \cdots & 0 \end{bmatrix} \tag{23}$$

Since the number n of states is equal to the degree of denominator $d(s)$, then the characteristics equation will be as Eq. (24):

$$s^n + d_1 s^{n-1} + \cdots + d_{n-1}s + d_n = 0 \tag{24}$$

According to Eqs. (21)–(23) the system transfer function can be written as Eq. (24) to Eq. (26) respectively:

$$\dot{x} = \underbrace{\begin{bmatrix} -1 & 1 & 1 \\ -1.64 & 0 & 1 \\ -0.64 & 0 & 0 \end{bmatrix}}_{A} x + \underbrace{\begin{bmatrix} 0 & 0 \\ 0.28 & 0.36 \\ 0.28 & 0.36 \end{bmatrix}}_{B} \underbrace{\begin{bmatrix} u_1 \\ u_2 \end{bmatrix}}_{u} \tag{25}$$

$$y = \underbrace{\begin{bmatrix} 1 & 0 & 0 \end{bmatrix} x}_{C} \tag{26}$$

4.2 Design Procedure of the SFC via Pole Placement Technique

Feeding back each state variable to the two inputs u_1 and u_2 gives Eq. (27):

$$u = -k_{mn}x \tag{27}$$

where k is the feedback gains express as:

$$k_{mn} = \begin{bmatrix} k_{11} & \cdots & k_{1n} \\ \vdots & \ddots & \vdots \\ k_{m1} & \cdots & k_{mn} \end{bmatrix} \tag{28}$$

Hence the feedback gains matrix is can also be written as Eq. (29):

$$k = \begin{bmatrix} k_{11} & k_{12} & k_{13} \\ k_{21} & k_{23} & k_{23} \end{bmatrix} \tag{29}$$

Using Eqs. (11) and (25) the system matrix $A - BK$ for the closed loop will be:

$$A - BK = \begin{bmatrix} -1 & 1 & 0 \\ -(7*k_{11})/25 - (9*k_{21})/25 - 41/25 & -(7*k_{12})/25 - (9*k_{22})/25 & 1 - (9*k_{23})/25 - (7*k_{13})/25 \\ -(7*k_{11})/25 - (9*k_{21})/25 - 16/25 & -(7*k_{12})/25 - (9*k_{22})/25 & -(7*k_{13})/25 - (9*k_{23})/25 \end{bmatrix} \tag{30}$$

Now closed loop system characteristic equation will be as shown in Eq. (31):

$$\begin{aligned} \det[SI - (A - BK)] = {} & \sum_{n=1,3} \left(\frac{7*k_{1n}}{25} + \frac{9*k_{2n}}{25} \right) s \\ & + \left\{ \left(\sum_{n=2}^{3} \left(\frac{7*k_{1n}}{25} + \frac{9*k_{2n}}{25} \right) + 1 \right) + s \right\} s^2 \\ & + \frac{1}{25} \{ (s(41 + 14k_{12} + 18k_{22})) + 16 \} \\ & + \frac{1}{25} \sum_{n=1}^{3} (7*k_{1n} + 9*k_{2n}) = 0 \end{aligned} \tag{31}$$

The desired-characteristic equation is in the form:

$$s^n + d_{n-1}s^{n-1} + d_{n-2}s^{n-2} + \cdots + d_2 s + d_1 s + d = 0 \tag{32}$$

where, d_i is are the desired coefficients.

For better transient response overshoot of $\leq$4.3% and 5.3 s settling time must be produced. The characteristic equation for the dominant poles is gives as Eq. (33) using the design parameters ξ as 0.693 and w_n as 1.082:

$$s^2 + 1.5s + 1.1709 = 0 \tag{33}$$

where dominant poles location is at $-0.75 \pm j0.78$, the third pole is $\approx$10 times the distance from the imaginary axis. while at -0.55 the closed-loop system desired characteristic equation was found to be:

$$s^2 + d_{n-1}s^{n-1} + d_{n-2}s^{n-2} + \cdots + d_2 s + d_1 s = 0 \quad (34)$$

Comparing Eq. (31) with Eq. (34) and matching their coefficients, the k_{mn}'s could be evaluated as follows:

$$\begin{aligned} &k_{11} = -1.4081, \quad k_{12} = 0.4737, \quad k_{13} = 0.9397, \\ &k_{21} = -1.8104, \quad k_{22} = 0.6091 \quad \text{and} \quad k_{23} = 1.2082 \end{aligned} \quad (35)$$

The MATLAB coding used for the controller design and implementation on the system is:

```
g=[tf([0.28 0.28],[1 1 1.64 0.64]) tf([0.36 0.36],[1 1 1.64 0.64])]
sys2=tf2ss(num,d/'en)
a=[0 1 0;0 0 1;0 -171 -101.71]
b=[0 0;0.28 0.36;0.28 0.36]
c=[1 0 0;0 1 0;0 0 1]
d=[0 0;0 0;0 0]
plant=ss(a,b,c,d)
p=[-0.55 -75-0.78j -0.75+0.78j]
k1=place(a2,b2,p1)
cl_sys=feedback(plant,k1)
step(cl_sys)
```

Encouraging values of k_{mn}'s are obtained while running the MATLAB codes, which are the same as the computed.

4.3 Controllability System Test

The aspect of controllability C_M in system is widely established [20, 21]. According to Sinha [22] for an nth-order plant whose state equation is as in Eq. (12) then the totally controllability can generally be expressed as Eq. (36):

$$C_M \left[B \vdots AB \vdots A^2 B \ldots A^{n-1} B \right] \quad (36)$$

Similarly, the 3rd order system controllability is as shown:

$$C_M = \left[B : AB \ \ A^2 B \right] \quad (37)$$

$$C_M = \left[\begin{array}{cc:cc:cc} 0 & 0 & 0.28 & 0.36 & 0 & 0 \\ 0.28 & 0.36 & 0.28 & 0.36 & -0.4592 & -0.5904 \\ 0.28 & 0.36 & 0 & 0 & -0.1792 & -0.2304 \end{array}\right] \quad (38)$$

Whereby the rank of C_M is equal to the number of linearly independent rows or columns. The rank can also be found by finding the highest-order square sub matrix that is non-singular. The determinant of the submatrix, which includes for example 2nd, 3rd and 4th column of C_M is not zero then the 3 by 3 matrix is non-singular, hence the rank of C_M is 3. It can be concluded that the system is controllable since the rank of C_M is equal to the system's order. Thus, the poles of the system can be placed using state-variable feedback design, which can be prove as:

```
A=[-1 1 0; -1.64 0 1; -0.64 0 0]
B = [ 0  0; 0.28 0.36; 0.28 0.36]
Cm=ctrb(A,B)
Rank=rank(Cm)
Ans=3
```

thus, the system is controllable.

5 Result and Discussion

Figure 12 shows the controlled vehicle's output speed with and without the SFC controller. The speed of the controlled vehicle with the SFC gave a smooth path with a precise tracking that has no oscillation as against that without SFC.

Figure 13 shows the acceleration response where the controlled vehicle with SFC gave the most acceptable acceleration of 2 ms^{-2}, while the acceleration of the controlled vehicle without SFC gave a value more than the accepted acceleration. Hence the acceleration with SFC is the accepted value [23].

Figure 14 shows the achievement recorded in terms of jerk in the controlled vehicle's jerk. A zero-jerk value (0 ms^{-3}) was recorded in the controlled vehicles jerk as seen in Fig. 14. This signifies maximum comfort in the controlled vehicle during the convoy movement.

6 Conclusion and Future Work

In this chapter, the use of IoV and state feedback controller for two-vehicle look-ahead convoy system was presented. The architecture of the system was discussed

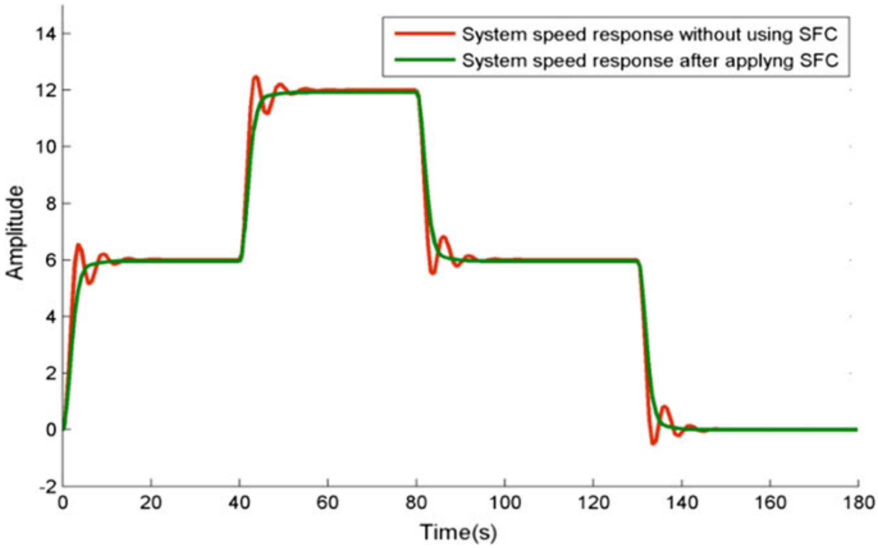


Fig. 12 Following vehicle's speed response with and without SFC

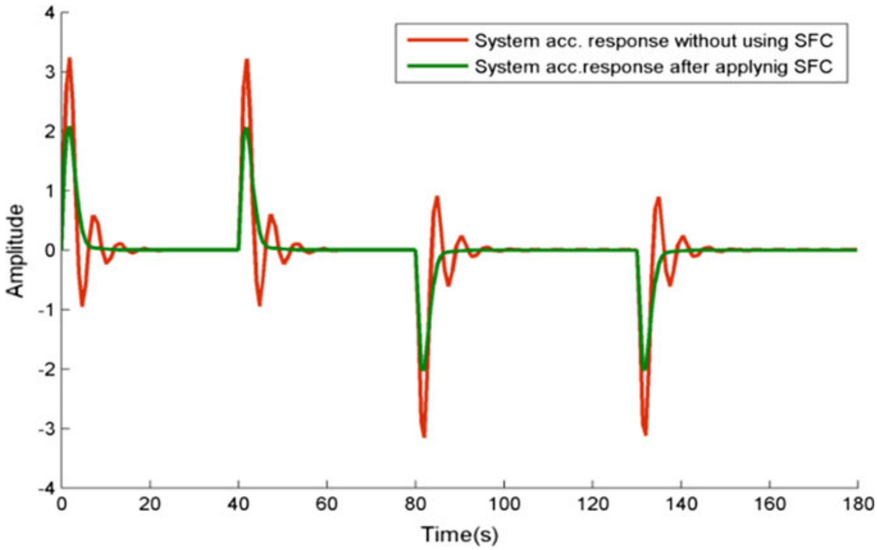


Fig. 13 Following vehicle's acceleration response with and without SFC controller

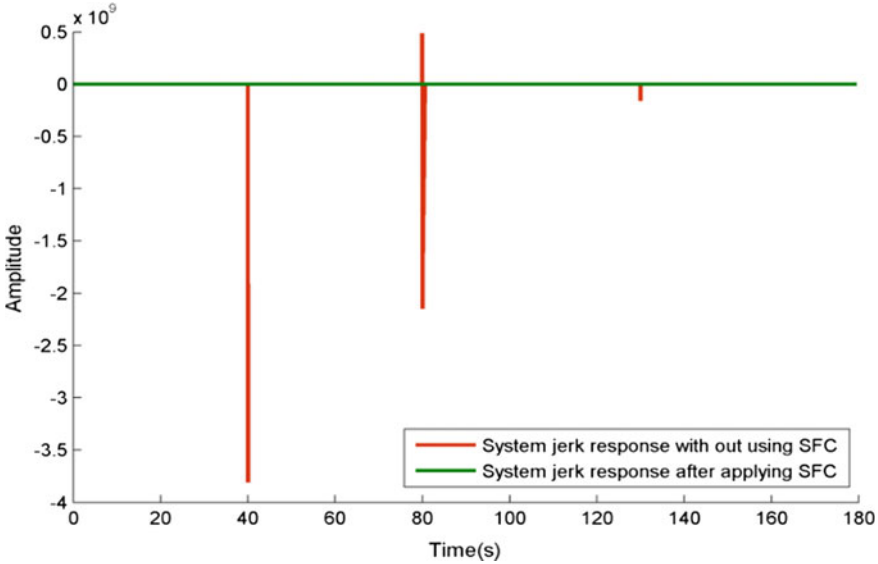


Fig. 14 Following vehicle's jerk response with and without SFC controller

and best system response was derived. The best system response was achieved with the design parameters of 0.28 for kp_1 and kv_1 and 0.36 for kp_2 and kv_2, respectively, which can be seen in Figs. 6 and 7. The state feedback controller design using pole placement technique for the two-vehicle look-ahead convoy system was designed and implemented. The overall performance of the vehicle convoy was analyzed in term of speed, acceleration and jerk and a comparative test was conducted with respect to the convoy with SFC against that without SFC. An improvement was achieved in the convoy behavior with SFC, such improvements included perfect tracking of speed by the controlled vehicle without amplifying the lead-vehicle oscillation off stream as seen in Fig. 12. Hence, stable string was achieved. Acceptable acceleration of 2 ms^{-2} was achieved with the SFC whereas non-accepted acceleration was observed in that without SFC as seen in Fig. 13. Passengers' comfort is achieved with no jerk associated with the controlled vehicle as seen in Fig. 14. In future work we shall explore how the SFC as a service can be deployed on the network server.

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