Fuzzy Logic Based-Skyhook Scheme With Firefly Algorithm for Semi-Active Ride Comfort

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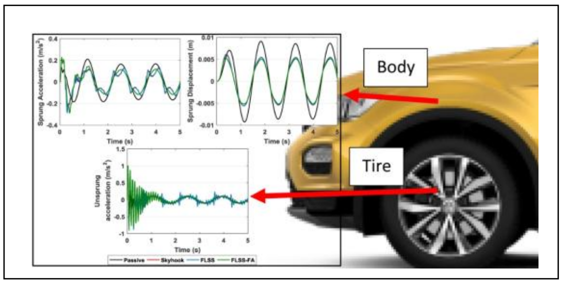
Graphical Abstract



Abstract

This study presents the effect of the applying fuzzy logic based-skyhook scheme tuned using firefly algorithm (FLSS-FA) for semi-active ride comfort the vehicle system. Spencer model is used as the magnetorheological damper model. The fuzzy logic control adopted with the skyhook policy based on Sugeno-type fuzzy was used to enhance the ride performance. An intelligent evolutionary algorithm known as the firefly algorithm (FA) was also adapted in the proposed controller to compute the fuzzy gain scaling. The performance of the FLSS-FA controller is compared to the FLSS, and continuous skyhook in the form of time domain analysis. Results indicate that the proposed FLSS-FA control gives better performance and able to improve the vehicle ride comfort that its counterparts.

Keywords

Firefly algorithm; fuzzy logic; ride comfort; semi-active suspension; skyhook

Introduction

Most modern car today relies on a number of electronic control systems. There are many type of controller that able to have an intelligent behaviour to make it a better system of the suspensions. These controllers are already can be found on breaking control, suspension control etc. The purpose of the sys-tem is to enhance the driving experience involving handling, safety and driving comfort. In most basic form, suspension consist of a couple components which are springs and shock absorbers. Under normal condition, the springs support the body of the car evenly by compressing and expending with every up-and-down movement after hit the bump. However, the movement gives unpleasant experience to the passenger and the effect is reduced by the shock absorber [1].

Latest trend of research on suspension system mainly focuses on the controller strategies as well optimization process. Previous controller done by research such as skyhook control [2], fuzzy logic control [3], neural network control [4] and optimal control [5] have been successfully published. The conventional skyhook as introduced by Karnop is one of the effective easy to be used.

However, the skyhook is mainly utilized to suppress body movement. Thus, the combination of other controllers with the skyhook control is one of the solutions that could be addressed in order to improve the controller performance. Previously, Ubaidillah and his team [6] presented the combination of the fuzzy logic based on skyhook controller and its performance has proven better than the conventional skyhook. However, in their research, no fuzzy gain scaling is considered since it is one of the important parts need to be considered due to be as a sort of context information [7]. Thus, in order to optimize the gain parameters, an intelligent optimization techniques based on evolutionary algorithm is used since it is very powerful and able to compute the controller with high performance level.

The intent of this research is to investigate the effect of the fuzzy logic based skyhook scheme (FLSS) controller tuned using the evolutionary algorithm based of the firefly algorithm (FA) technique to optimize the parameters of the said controlleras well as able to have a good ride comfort.The semi-active controller, namely skyhook, FLSS and FLSS-FA controllers are investigated in this study.

The paper begins with the Section 1 which is covers on introduction of the semi-active suspension system with MR damper and review on the previous works done by other researchers. Section 2 explains the modelling of the system, the Section 3 describes the controller approach used in this study including the explanation and strategy of the optimization technique. Analysis and discussion is presented under Section 4 and the Section 5, conclusion is presented.

SEMI-ACTIVE AND MR DAMPER SYSTEM

The view structure of the whole model for semi active system can be represented by using the following equation:

$$m_s\ddot{x}_s + F_d - k_s(x_u - x_s) = 0 (1)$$

$$m_u\ddot{x}_u + F_d - k_s(x_u - x_s) - k_t(x_r - x_u) = 0 \ (2)$$

where the mass of the body and the tire of the body are represented by $m_s$and m_u, respectively.

Road profile can be defined asx_r, displacement of the body is known as, x_s while the spring and tire stiffness are known as k_s and k_t, respectively. At last, F_d is known as output force. All parameters used in this study are taken from previous work as shown in Table 1.

Table 1: Full scale parameter [8]

Parameter	Value
Sprung mass, m_s	338.5 kg
Unsprung mass, m_t	59 kg
Spring stiffness, k_s	15000 N/m
Tire stiffness, k_t	190000 N/m

An overview structure model for semi active including the use of Spencer model is also depicted as in Figure 1.

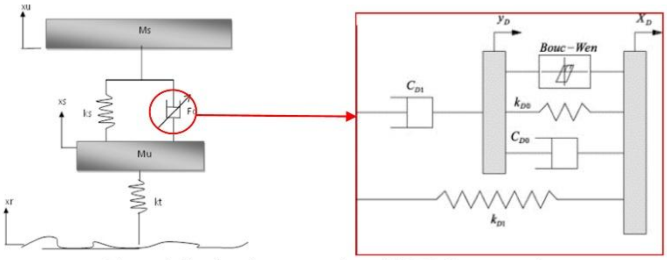


Figure 1: Overview model

The MR damper modelling is done by using a Spencer model approach that has been validated by previous work [9]

CONTROL DESIGN AND OPTIMIZATION

Fuzzy Logic based Skyhook Scheme (FLSS)

Since the conventional skyhook controller is unable to consider the movement between sprung and unsprung masses, the use of the FL is a good approach to solve this problem. The FL is good to handle such a need due to fact that it is able to be identified since it is consider the direction movement of the deflection damper [10]. In this study, the inputs of the FL control are relative velocity of the body and body velocity while the output is the damping coefficient based on the skyhook policy. Several types of the shapes for fuzzy system have been widely used in any applications such Gaussian shape, Bell shape, Triangular shape and etc. Thus, in this study, the Trapezoidal membership function is randomly selected and used due to the most familiar shape that has been used in any applications previously. The fuzzy input for membership function is set to be as Negative (N), Zero (Z) and Positive (P). The shape of the membership function is shown in Figure 2.

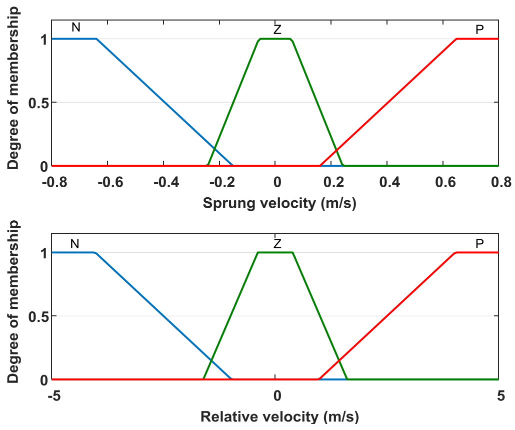


Figure 2: The trapezoidal shape

By using IF-THEN rule, the relationship among of the variable is defined by the following fuzzy rule:

$$\text{If } \dot{z}_s \text{ is } (A) \text{ and } \dot{z}_{rel} \text{ is } (B) \text{ then } C_d \text{ is } (C)$$

where the constant values of *A, B* and *C* are known as the body velocity, the relative velocity and the damper coefficient, respectively. The output of FL based on the damping coefficient is shown in Table 2.

Table 2: Fuzzy coefficient

C_{min}	C_{d1}	C_{d2}	C_{d3}	C_{d4}	C_{max}
700	3000	6000	9000	12000	15000

Since, the use of FL controller is based on the Sugeno Fuzzy type, the output damping coefficient can be related by the following linguistic variables:

$$V = (C_{min}, C_{d1}, C_{d2}, C_{d3}, C_{d4}, C_{max}) \quad (3)$$

where all the coefficients are defined as the range of below and upper damping state. The rules of the system are also being developedand it is shown in Table 3.

Table 3: Fuzzy rule

		Relative Velocity (RV)		
		N	Z	P
SprungVelocity (SV)	N	C_{max}	C_{d3}	C_{min}
	Z	C_{d4}	C_{d2}	C_{d1}
	P	C_{min}	C_{d2}	C_{max}

Since, the output of the outer loop controller should be damping force, the relationship equation based on the skyhook scheme is describes as follows:

$$F_d = C_d \dot{z}_{rel} \quad (4)$$

It is also important to study the integration of the gain scaling for each input and output of the said controllers. Thus, in this study, all the said gains are intercorporate with the fuzzy logic as a sort of context information as well as to improve the accuracy of the control system. The said gains are defined as the gain of the body velocity (*GSV*), the relative velocity gain (*GRV*) and the coefficient of gain controller (*GC*). To compute the optimum values of all gains, an intelligent optimization approach based on the FA strategy is used in this study.

Firefly Algorithm (FA)

In a practical problem, metaheuristic algorithm becomes an interesting strategy that could be used in order to optimize the parameters. The FA is one of the metaheuristic algorithm that has been previously discussed and used to compute any parameters in different applications. It is very efficient and able to solve with up to dynamical and global optimization problem[11].The FA begins with an introduction of the particles (firefly) which is based on the population and its concept is need to fine their best mate according to the light intensity. The process of the finding the mates is must follow the rules, which are the partners are unisex, the firefly finds the mate which brighter than itself. If no one brighter, the firefly is move randomly. The process of finding mates is based on the fitness function (light intensity). Its behaviour obeys the rules follows:

$$I\alpha\frac{1}{r^2} \qquad (5)$$

The attractiveness (β) of the firefly is proportional to the attractiveness and it can be represented in terms of equations as:

$$\beta(r) = \beta_0 e^{-\gamma r^m}, m \geq 1 \qquad (6)$$

where distance between the particles is known as r, β_0 is attractiveness with zero distanceγ is the fixed light absorption coefficient. The distance between a couples of fireflies i and j at x_i and x_j, respectively, is the Cartesian distance is expressed as

$$r_{ij} = \|x_i - x_j\| = \sqrt{\sum_{k=1}^{d}(x_{i,k} - x_{j,k})^2} \qquad (7)$$

where $x_{i,k}$ is the k^{th} component of the spatial coordinate x_i of i^{th} firefly and d is the number of dimension. The movement of a firefly i when attracted to another more attractive (brighter) firefly j can be defined as:

$$x_i = x_i + \beta_0 e^{-\gamma r_{ij}^2}(x_j - x_i) + \alpha\varepsilon_i \qquad (8)$$

where α is the random parameter, ε_i is a vector of random numbers drawn from a Gaussian distribution of uniform distribution. As a normal parameters, β can be used as 1 and $\alpha \in [0, 1]$. The step of the firefly algorithm can be represented based on the pseudo code as shown as in Figure 3.

```
Objective Function, f(x), x = (x_1, ....., x_d)
Generate initial population of fireflies, x_i (i = 1,2, ....., n)
Light intensity I_i at x_i is determined by f(x_i)
Define light absorption coefficient
while (t < MaxGeneration)
      for i = 1 : n ( all n fireflies)
            for j = 1 : i (all n fireflies)
                  if (I_j > I_i), move firefly i towards j in d-dimension; end if
                  Attractiveness varies with distance r via exp [-r]
                  Evaluate new solutions and update light intensity
            end for j
      end for i
Rank the fireflies and find the current best
end while
Post process results and visualization
```

Figure 3: The pseudo code of FA

In this study, the firefly generation is set to be 200, the firefly size is 10, alpha, α is 0.25, beta, β is 0.8 and gamma, γ is 1. The optimization process of the FLSS gain scaling is computed based on the lowest MSE value. The integration of the FA and FLSS control system is shown in Figure 4.

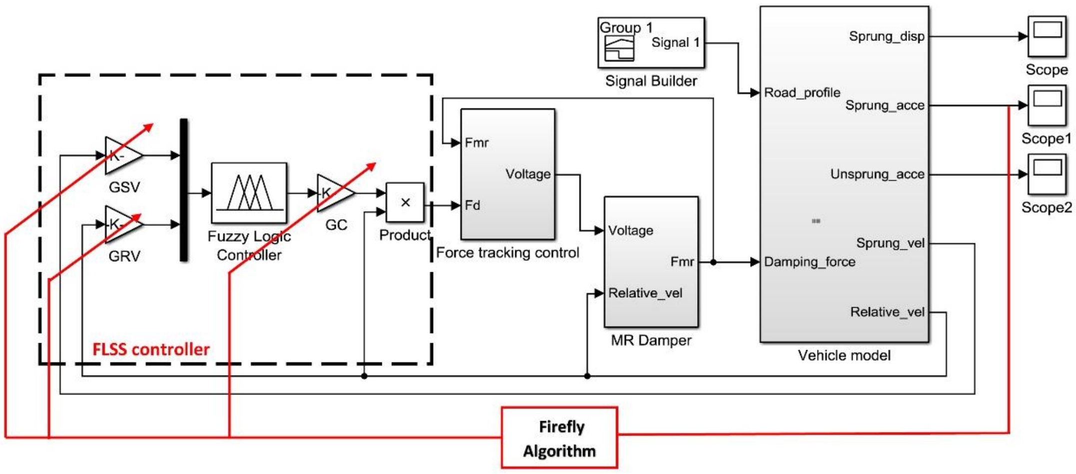


Figure 4: The FLSS-FA control design

The FA optimization results in computing the parameters is also shown in Figure 5.

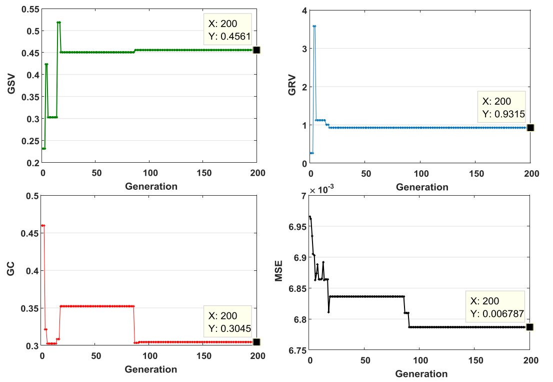


Figure 5: The optimization performance of the gains

Analysis and Discussion

Taking the 0.7 Hz frequency (0.005 m amplitude) of sinusoidal as an input, the error and the improvement for all controllerare tabulated in Table 4.

Table 4: Overall results

Index	Passive	Skyhook	FLSS	FLSS-FA
Sprung acceleration (m/s^2)	0.0124	0.0071 (42.7%)	0.0070 (43.5%)	0.0068 (45.2%)
Sprung displacement (m)	3.04×10^{-5}	1.33×10^{-7} (56.3 %)	1.31×10^{-7} (56.9 %)	1.19×10^{-7} (60.9 %)
Unsprung acceleration (m/s^2)	0.0104	0.0265 (-55 %)	0.0286 (-75 %)	0.0306 (-94 %)

Referring to the table, the semi-active with the proposed controllers have shown a good respond. It is proven that, the proposed FLSS-FA controller shows a good response and manage to improve the ride comfort of the vehicle (sprung acceleration analysis) with up to 45.2 % reduction. For analysis of body displacement response, it can also be mentioned that the proposed FLSS-FA has significantly improve the body amplitude with up to 60.9 % over the passive system. For unsprung acceleration analysis, there are no improvement can be made for all semi active control systems. Hence, the controller design has a right track since all the forces has been transferred to the sprung position in order to maintain the body amplitude. For controller's comparison, the FLSS-FA has slightly improved the vehicle performance for both sprung acceleration and sprung displacement analyses as compared to the FLSS and skyhook controllers. All results can be obtained in time domain as shown in Figure 6.

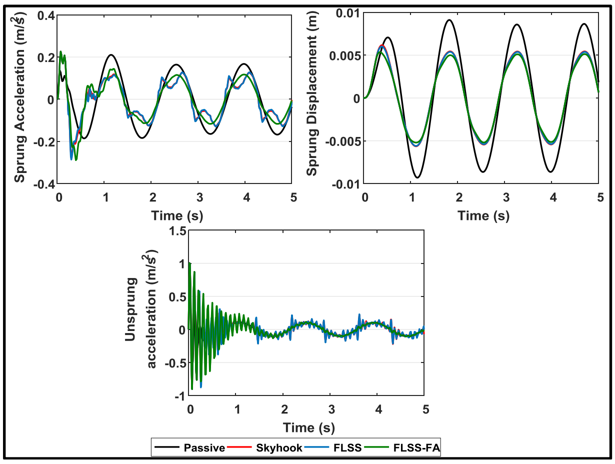


Figure 6: Time domain responses

Conclusion

This presents the investigation of the FLSS controller with FA strategy in order to improve the vehicle ride comfort. The semi-active based on the quarter vehicle model has been developed and fitted with the MR damper system. Taking the body acceleration, body displacement and tire acceleration as the parameters of interest, results indicates that, the proposed controller managed to improve the vehicle ride comfort with up to 45.2 % when the input of the system is set a 0.7 Hz sinusoidal disturbance. The integration of the FA strategy to the FLSS controller also manage to have a slightly improvement when it is compared to the FLSS itself as well as the skyhook controllers.

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