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PID and ANFIS based Control of Semi-Active Suspension System using Different Membership Functions

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ABSTRACT:

This study considers proportional-integral-derivative (PID) and adaptive neuro fuzzy inference system (ANFIS) controllers for stabilizing extremely dynamic semi-active suspension of quarter-car model. The free-body-diagram analysis was conducted and system was then simulated in Matlab-Simscape using PID controller. The results of PID were acquired as inputs for ANFIS controller. The ANFIS controller was trained via three different membership functions (MFs) namely triangular, trapezoidal and Gauss. The results clearly demonstrate that MF shape effects the learning of ANFIS. The fallouts highlight superior responses of ANFIS technique then PID. Moreover, ANFIS controller designed using Gauss shape MF performed better than other shaped MFs.

KEYWORDS:

Proportional-integral-derivative control; Simscape; Semi-active suspension; Membership functions

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NOMENCLATURE:

ANN	Artificial neural network
PID	Proportional-integral-derivative
MF	Membership function
m_1	Sprung mass
k_1	Spring constant
m_2	Unsprung mass
k_2	Tyre constant
$\dot{x}_1$	Sprung mass velocity
b_s	Damping coefficient
$\dot{x}_2$	Unsprung mass velocity
K_p	Proportional gain
$\ddot{x}_1$	Sprung mass acceleration
K_i	Integral gain
$\ddot{x}_2$	Unsprung mass acceleration
K_d	Derivative gain
m	Gradient
M	Jacobian matrix
e	Network error
T	Transposition

1. Introduction

Suspension system is a vital mechanism that provides comfort and improved handling to a vehicle [1, 2]. these systems play an important role in minimizing vibrations caused by irregular road surface and driving conditions [3]. Machine learning techniques play a key role in various control applications [4, 5]. Moreover, in the past few decades various intelligent controllers have been developed for vibration suppression in suspension systems [6, 7]. For instance, a comparatively cheaper semi-active suspension using Artificial neural networks (ANNs) has been developed by researchers in the past [8, 9]. The ANN controller was used for controlling the valve opening for required damping. The system was initially controlled using a proportional integral derivative (PID) controller and the results thus acquired were used for ANN learning [10]. The fallouts of ANN controller were further compared to that of commercial magneto-rheological damping systems. The outcomes demonstrate superior performance of ANN controller with lesser vibration and quicker responses [11, 12]. In the past, researchers have proposed a rule-based technique for improving the design of semi-active suspensions [13].

The tire deflection data of the wheels were considered for quantifying the behaviour of the system. The findings highlight that the controller resulted in minimal tire deformation over different frequency ranges [14, 15]. The experiments confirmed that rule-based controller has successfully reduced the root mean square unsprung acceleration up to 11%. Furthermore, researchers also considered fuzzy logic controller for stabilizing a magneto-rheological damper [16, 17]. The fuzzy logic controller was considered for obtaining the desired control force for the magneto-rheological damper. The fallouts indicate that incorporating the magneto-rheological damper with a fuzzy controller has improved its behaviour [18]. Moreover, the suspension working space, acceleration, tyre deflection and jerks has been significantly reduced using proposed controller. It was investigated a reinforcement adaptive control technique for designing of a complete vehicle active suspension in the past [19]. In order to overcome the complexities associated with conventional backstepping control strategies, the study considered a novel reinforcement learning technique designed using a deep deterministic gradient control approach. The findings highlight superior performance of proposed strategy compared to traditional passive suspension system and backstepping control techniques. Lately, researchers also proposed a combined technique incorporating a semi-active and active actuation for controlling the yaw, roll, pitch and heavy dynamics excitations of the vehicle [20].

To achieve the desired control, the study proposed a nonlinear model predictive control strategy with and without cost function weight adaptation. The strategy was compared with the passive suspension and combination of skyhook and active roll technique. The results clearly indicate superior performance of nonlinear model predictive control strategy compared to other control strategies. This work demonstrates PID and ANFIS techniques for controlling highly nonlinear and multivariable semi-active quarter-car suspensions. The free-body-diagram of the system has been initially developed and replicated in Matlab-Simscape using PID controller. The results of PID controller were used as inputs for ANFIS which was trained via three different MFs namely triangular, trapezoidal and Gauss. The type of MF plays an important role in determining training error of ANFIS. Therefore, there is an urge for identifying the appropriate shape of MF which could yield the most optimal training results. The outputs attained for different MF of ANFIS were monitored in terms of settle time and overshoot responses.

2. PID controller design

The system includes a sprung mass (m_1) and unsprung mass (m_2) fixed together with the help of spring and dampers as shown in Fig. 1 [21]. The final equations for forces acting on the masses are shown with the help of Eqns. (1) and (2) respectively [22]. Where, $\dot{x}_1$ and $\dot{x}_2$ signifies the velocity of the sprung and unsprung mass respectively. Likewise, $\ddot{x}_1$ and $\ddot{x}_2$ denotes the acceleration of the respective masses. Whereas, k_1 and k_2 are constant of spring and tyre respectively and $ƀ_s$ denotes the damping coefficient. Additionally, the magnitude of different attributes considered for analysis were sprung mass (m_1 = 540kg), unsprung mass (m_2 = 60kg), spring (k_2 = 5800N/m), damper coefficient ($ƀ_s$ = 300Ns/m) and tyre stiffness (k_2 = 140000N/m). The Matlab-Simscape model developed using the equations are shown in Fig. 2. The PID controller for the system has been tuned using Ziegler-Nicholas method [23]. Initially, the magnitude of integral (K_i) and derivative (K_d) gains were set to zero and the proportional gain (K_p) was set to a value that generated a sustained oscillation. Further, the proportional gain was steadily increased until the system output starts to oscillate at critical gain point (K_p). The final values of PID gains obtained after tuning were K_p = 327.013, K_i = 334.068 and K_d = 83.517.

$$m_1\ddot{x}_1 = -k_1(x_1 - x_2) - ƀ_s(\dot{x}_1 - \dot{x}_2) \quad (1)$$

$$m_2\ddot{x}_u = k_1(x_1 - x_2) + ƀ_s(\dot{x}_1 - \dot{x}_2) - k_2(x_2 - x_{in}) \quad (2)$$

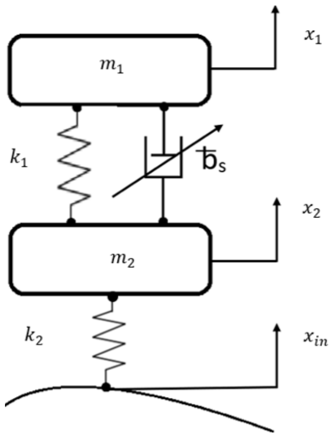

Fig. 1: Free-body-diagram of semi-active suspension

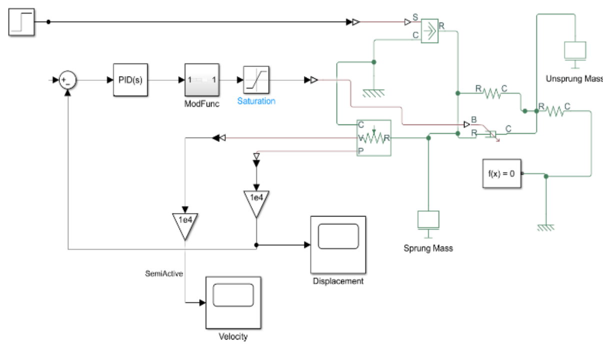

Fig. 2: Simscape model of the system

3. ANFIS controller design

ANFIS model is trained adopting the outcomes of the PID controller. ANFIS imbibes the feature of learning of artificial neural networks and application of rule-based logic of fuzzy controllers [24]. It has been trained by means of 3 different MFs namely triangular, trapezoidal and Gauss [25]. The ANFIS model has been trained using Leven berg-Marquardt algorithm which is widely used for solving nonlinear least square problem. It does not incorporate the Hessian matrix and gradient (m) can be formulated as,

$$m = M^T e \quad (3)$$

Where, m represents the gradient, M is the Jacobian Matrix, e is the network error and T is the transposition. The loaded samples in ANFIS for training is illustrated in Fig. 3. Further, the Matlab-Simscape model incorporated with ANFIS controllers with different membership functions are shown in Fig. 4. A view of training errors obtained after learning for ANFIS controller designed using triangular, trapezoidal and Gauss membership functions are shown in Fig. 5. The least training errors were obtained using Gauss MF, followed by triangular and trapezoidal shape MF. The errors obtained after training in ANFIS using triangular, trapezoidal and Gauss shape MF were 4.91, 6.82 and 3.83 respectively.

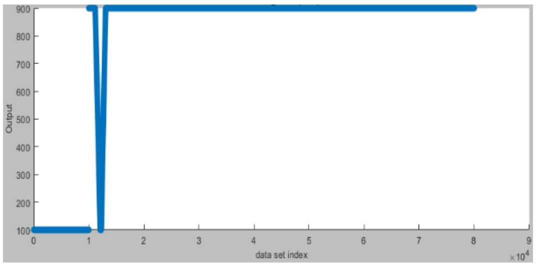

Fig. 3: Loaded samples in ANFIS

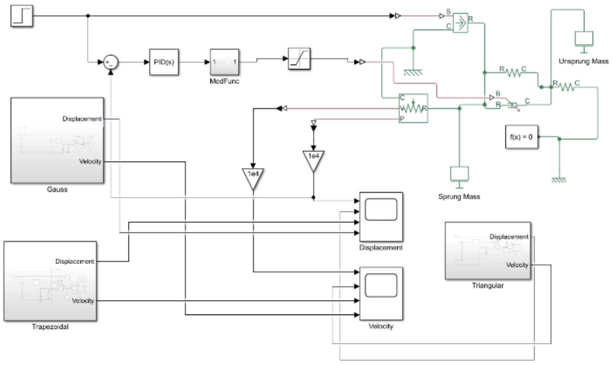

Fig. 4: Simscape model incorporated with ANFIS controllers

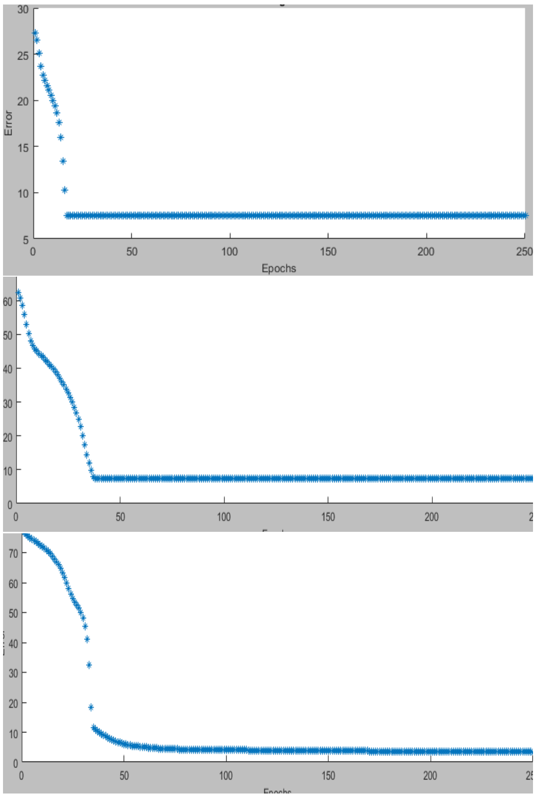

Fig. 5: Plots obtained for training errors in ANFIS using triangular (top), trapezoidal (middle), Gauss MF (bottom)

4. Results and discussion

The outcomes obtained after simulation of semi-active suspension system using ANFIS controller designed using different membership functions are shown with the help of Figs. 6 and 7 respectively. It is indicative from the outcomes that the percentage overshoot responses have been improved using ANFIS model with Gauss MF. Moreover, the settling time remains unchanged compared to that of PID. It is indicative from outcomes that the percentage overshoot responses increase by 1m/s using ANFIS. Alternatively, the settle time is significantly reduced using Gauss MF. A comparison of results obtained for the system using PID and ANFIS controller with different MFs are given in Table 1.

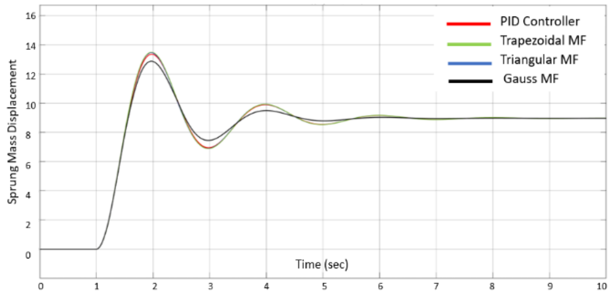

Fig. 6: Sprung mass displacement using PID and ANFIS controller designed using different MFs

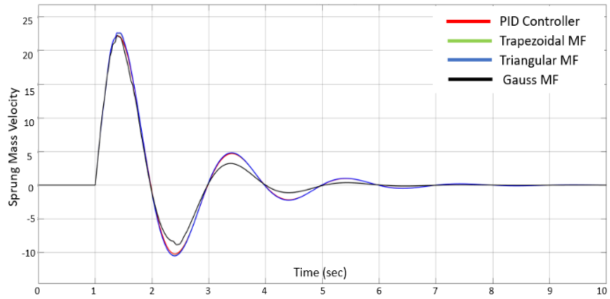

Fig. 7: Sprung mass velocity using PID and ANFIS controller designed using different MFs

Table 1: Comparison of results

Controller	Sprung mass displacement		Sprung mass velocity (m/s)	
	% overshoot	Settling time (s)	Max. overshoot	Settling time (s)
PID	52.9	7.0	22	7.0
Triangular MF	52.9	7.0	23	6.0
Trapezoidal MF	52.9	8.0	23	8.0
Gauss MF	47.05	7.0	23	5.0

5. Conclusions

The study demonstrates ANFIS for stabilizing extremely dynamic quarter car semi active suspensions. The free body diagram model has been developed and successfully simulated in Matlab-Simscape platform. The model was initially controlled via PID controller and the results were collected for training of ANFIS controller. In order to analyses the effect of shape of MF on learning of ANFIS, it has been designed using triangular, trapezoidal and Gauss shape MFs. The results clearly highlight comparatively superior performance of ANFIS controller designed using Gauss shape MF. Further, the percentage overshoot responses have also been reduced using ANFIS controller designed using Gauss MF.

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