iJET EXPLORE International Journal of Engineering & Technology
CENTRE OF PROFESSIONAL RESEARCH PUBLICATIONS
ISSN 2049-3444

International Journal of Engineering and Technology Volume 2 No. 3, March, 2012

Vehicle Suspension System Control by using Adaptive Fuzzy Controller

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ABSTRACT

Fuzzy logic based control systems provide a simple and efficient method to control highly complex and imprecise systems. However, the lack of a simple hardware design that is capable of modifying the fuzzy controller's parameters to adapt for any changes in the operation environment, or behaviour of the plant system limits the applicability of fuzzy based control systems in the automotive and industrial environments.

Adaptive control is the control method used by a controller which must adapt to a controlled system with parameters which vary or are initially uncertain. Despite the lack of a formal definition, an adaptive controller has a distinct architecture, consisting of two loops control loop and a parameter adjustment loop.

In this project automotive suspension system parameters are controlled by adaptive fuzzy logic controller and for which simulation results are obtained in MATLAB environment.

Keywords **— Suspension System, Spring Rate, Fuzzy logic controller.**

I. INTRODUCTION

Fuzzy logic controllers (FLC) offer a simple method to control highly complex and imprecise systems, without the need of an accurately detailed mathematical model of the controlled plant. Fuzzy logic provides a process for dealing with the uncertainties of these complex systems using a human type reasoning method with the use of linguistic variables which are evaluated by a set of IF-THEN type rules (a process similar to that of the human reasoning process). The similarity between the workings of fuzzy logic, and the fundamentals of the human thought process, allows the controller to capture the expert human knowledge and transform it into rules used to control the plant system. The relevance of fuzzy based control systems to a large number of industrial and automotive applications has motivated the research and development of such control systems using various hardware and software techniques. These techniques are generally classified into two categories: software solutions, using general-purpose microprocessors, and application-specific instruction processors (ASIPs); hardware solutions, using dedicated fuzzy processors, and application specific integrated circuits (ASICs). Traditionally, fuzzy controllers have been implemented using pure software methods on a general-purpose microprocessor with coupled reconfigurable hardware architecture in order to utilize the flexibility of the microprocessor with the performance of the reconfigurable hardware. This type of design provides a great flexibility with the definition of the fuzzy parameters (membership functions and inference rules), but the high power demand, and the area required for the complete architecture, make this type of design unsuitable for applications where the size of the controller is an important factor. Pure hardware designs on the other hand, have the advantage of satisfying the area, power, performance, and on a large enough production scale, cost requirements. The advancements in integrated circuit technologies and the emergence of new CAD design tools have defined ASIC based designs as a leader in hardware based systems.

II. THE PROPOSED FUZZY LOGIC CONTROL ALGORITHM AND SUSPENSION PLANT DESCRIPTION

A. Fuzzy Logic Control

The basic fundamental concept of fuzzy logic control is to describe a relationship between the system inputs and output in terms of degrees of membership and a set of IF-THEN fuzzy rules. Using these control parameters the fuzzy controller is able to stabilize the controlled system. To perform the required control operation, the fuzzy logic controller uses a set of fuzzy operations/stages (Fig.1), they are:

1) Fuzzification interface:

In fuzzy logic, there exist a number of different membership functions such as the triangular, trapezoidal (Fig. 2), bell, and Singleton shapes (Fig. 3).

These membership functions define the relationship between the "crisp" sensor input value, and it's corresponding fuzzy values. In this paper, the membership functions used to perform the conversion process are the trapezoidal, and triangular membership functions. Each trapezoidal function is defined using four points, and is divided into three segments as seen in Fig. 2. The Y axis shows the degree of membership as a value between 0 and 1, whereas the X axis displays the universe of discourse of the input variable. Note that for the triangular membership functions points (b) and (c) are the same. The input fuzzification process first requires determining the segment in which the crisp input value falls in, then calculating the degree of membership (□) according to equations (1-3). Once the degrees of membership are calculated for each input, the linguistic variables along with their membership degrees are passed to the rule base inference stage (Fig.1).

$$Segment\ 1 \Rightarrow \mu = \frac{Crisp\_Input - a}{b - a} \quad (1)$$

$$Segment\ 2 \Rightarrow \mu = 1 \quad (2)$$

$$Segment\ 3 \Rightarrow \mu = \frac{d - Crisp\_Input}{d - c} \quad (3)$$

2) Fuzzy rules inference:

In fuzzy logic control, the rules are considered as the knowledge of the expert in the plants dynamics. The fuzzy control rules take the form of an IF THEN statement as follows:

IF x is **A** and y is **B THEN Z** is C (4)

The rule seen in (4) describes a condition that the plant can exhibit at a given point using linguistic variables (x and y), and fuzzy sets (A and B).

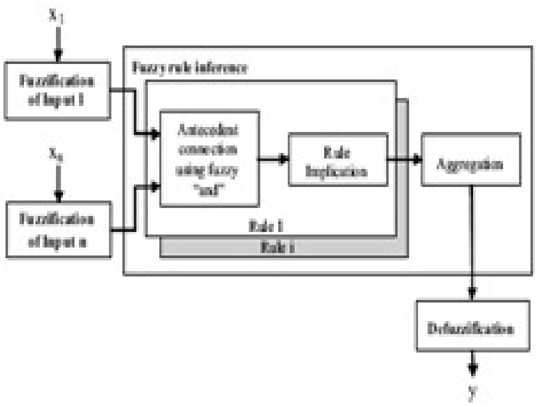

Fig. 1. Fuzzy logic control building blocks.

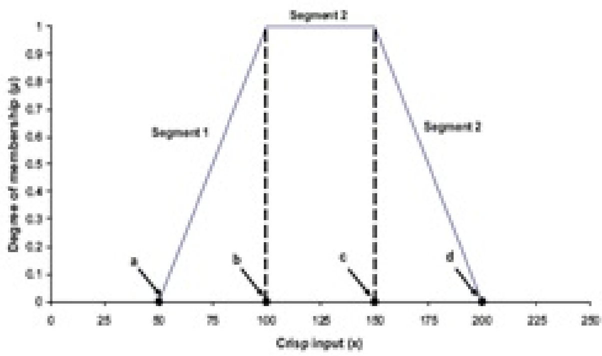

Fig. 2. Trapezoidal type membership function.

The "AND" operator in the fuzzy rule above is the minimum operation between the two fuzzy sets. This rule is used in the rule inference stage of the FLC to compute the degree to which the input data matches the condition of a given rule. The number of fuzzy control rules present in an FLC depends on the number of functions in the inputs membership functions; this relationship ensures that there is an active rule for every state that the plant can exhibit. Although these rules are mostly extracted from the designer's experience, or knowledge of the plants' dynamics, various types of optimization techniques are usually used to obtain these rules (such as genetic algorithms, or neural networks). These systems are usually referred to as adaptive fuzzy control systems.

3) Defuzzi fication interface:

The output of the rule inference stage is represented as conclusions with degrees of membership. Before the output can be passed to the plant it must be converted to a real crisp output value, hence the defuzzification stage is needed. Depending on the type of control, the accuracy required, and the type of the output membership function, there exist three main types of defuzzification methods:

Center of Maximum (COM) method.
Center of Gravity (COG) method.
Mean of Maximum (MOM) method.

The COG method is one of the most popular defuzzification methods due to its accuracy, it works by computing the area under the active membership functions , but the high accuracy of the method comes at the cost of increased computational and time and complexity. The COM method seen in (5) has been shown to provide similar if not equivalent accuracy to the COG method, when used with singleton type membership functions. The main advantage of this method is its computational simplicity. The mean of maximum method, is typically used in cases where the output variable has fixed non continuous values.

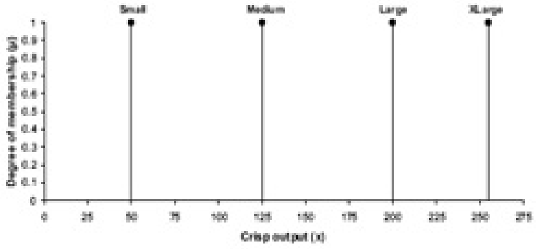

Fig. 3. Singleton type output membership function.

$$Crisp\_output(x) = \frac{\sum_{i=1}^{N} [\mu_i \times \mu_{i,mf}]}{\sum_{i=1}^{N} \mu_i} \qquad (5)$$

In this method, the output result corresponds to the maximum active membership function. Since the output membership functions used in this paper are represented as singletons (Fig. 3), and the output accuracy is important, the centre of maximum method is used. The choice of implementing the COM defuzzification method was made due to the short execution time, and low resources required for the implementation.

B. Vehicle suspension and optimal control systems

A quarter car semi-active suspension model with two degrees of freedom is implemented to test the behaviour of the proposed fuzzy logic controller. In order to stabilize the semiactive suspension system, a control system is needed to manage the variable damper in the system. Along with fuzzy logic control, researches have traditionally used optimal control theory to provide the control action necessary to stabilize the suspension system. Fig.4 shows the block diagram of the plant and control system. For comparison reasons a linear quadratic regulator was also implemented. For a full description of the suspension system, and the linear quadratic regulator the reader is referred to. Although, the simulations are performed on a quarter car model, the implementation method and results are still valid for the half car and full car models when controlled using the local control law.

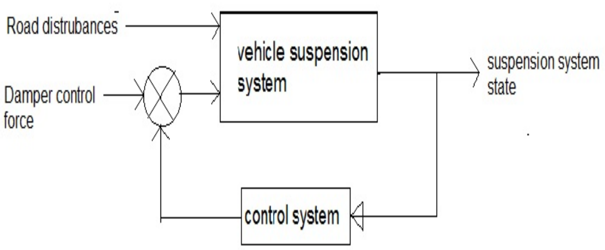

Fig: 4 Basic Black diagram of the plant using control system

III. SIMULATION & RESULTS

The total section III describes the simulation circuits and results for the vehicle suspension system by using the different type of controllers Fig:5 shows the block diagram for the vehicle suspension system by using the PI controller

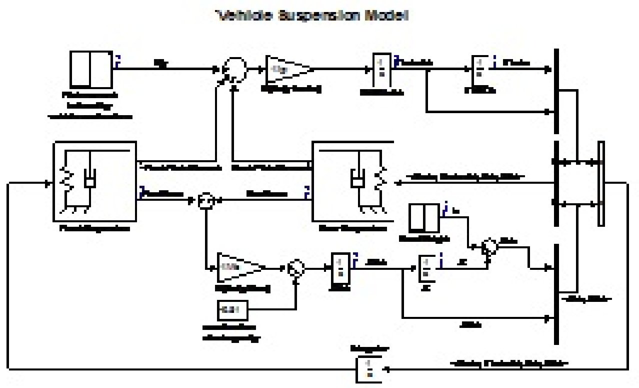

Fig: 5 vehicle suspension model with PI controller

The fig: 6 shows the output graph for that PI controller. PI controller is the classic technique by using this method we did not get the accurate results for the non linear plants. So by using of the some modern techniques get some more accurate results as compared with this PI controller. Preferred modern techniques are adaptive & fuzzy logic controllers.

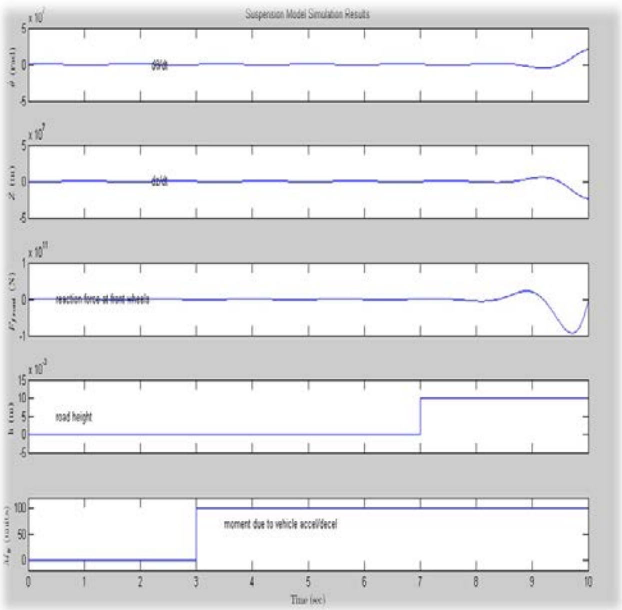

Fig: 6 Output graph for PI Controller

Using of Fuzzy controller some rules are to be performing these rules are from in FIS Editor Fig: 7 shows the FIS Editor.

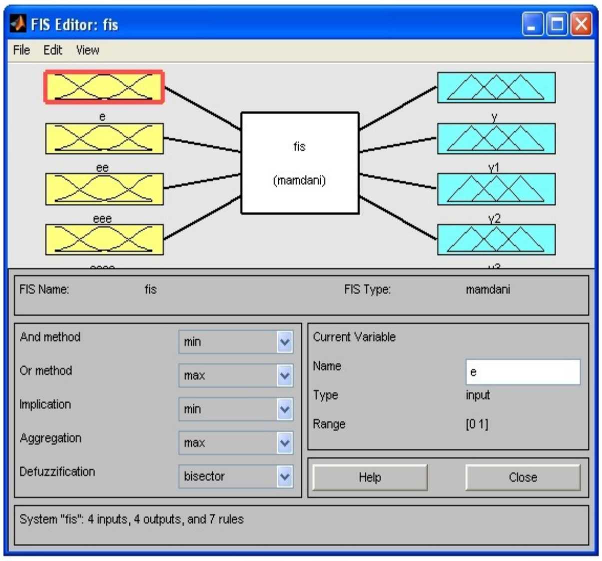

Fig: 7 FIS Editor

The vehicle suspension system by using the Fuzzy Logic controller show in the below fig 8.

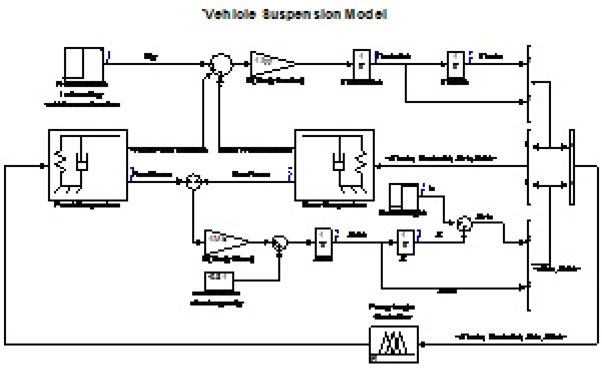

Fig: 8 Vehicle suspension model with FUZZY controller

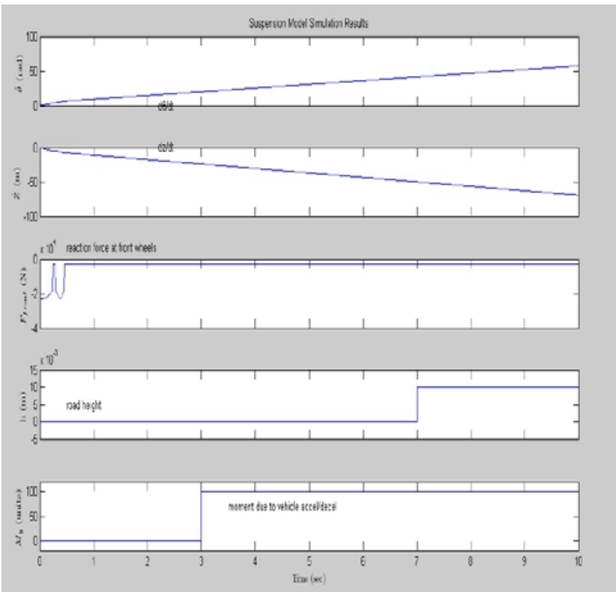

Fig: 9 Output Graph for Fuzzy controller

For running of adaptive control in MATLAB initially prams file should be run. Fig: 10 show that prams file Editor.

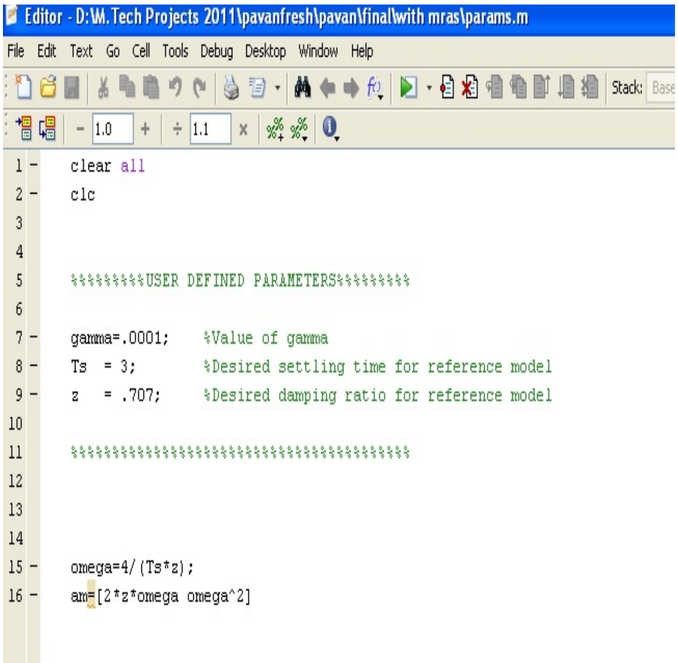

Fig 10: Params File Editor

The vehicle suspension system control can achieve by using Sliding Mode Control. Sliding Mode Control is the one of the adaptive Control technique shown in below fig.

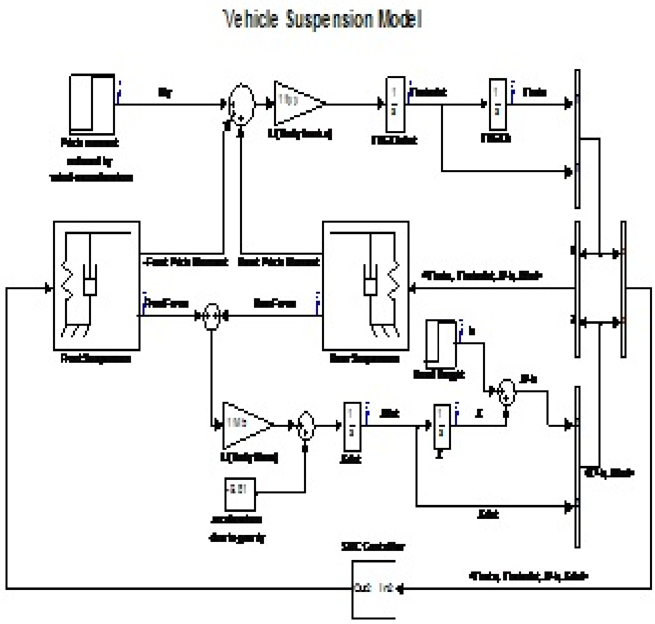

Fig: 11 Vehicle suspension model with Sliding mode control.

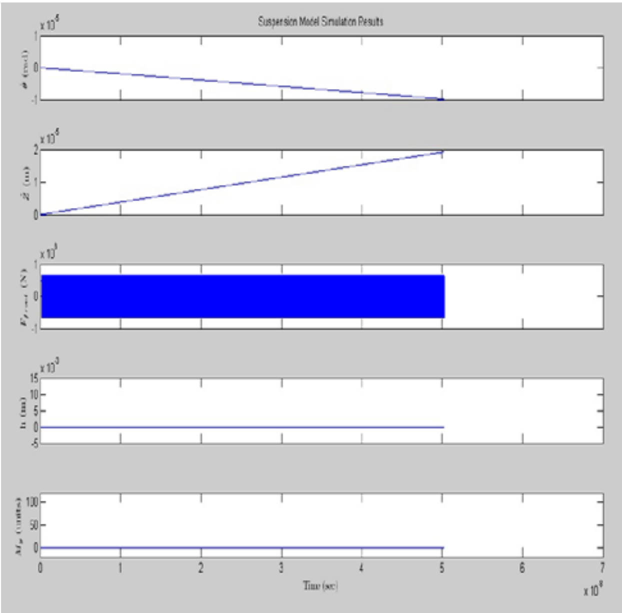

Fig: 12 Output Graph for Sliding Mode Control

Fig. 12 shows the output file for the SMC Controller and Fig 13 shows sub circuit for the SMC Control But by using of the Siding Mode Control (SMC) & Fuzzy Logic Control also some distortions are occurred. By the combination of FUZZY & SMC Control some more accurate results are obtained. Fig 14 shows the vehicle suspension system control by using SMC & Fuzzy Logic Controller and Fig 15 shows the Result graph for that Hybrid Controller.

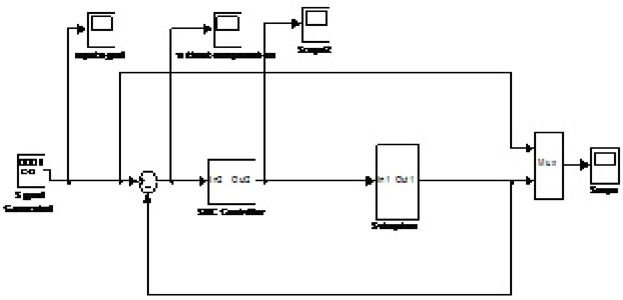

Fig: 13 Sub circuit for Sliding Mode Controller (SMC)

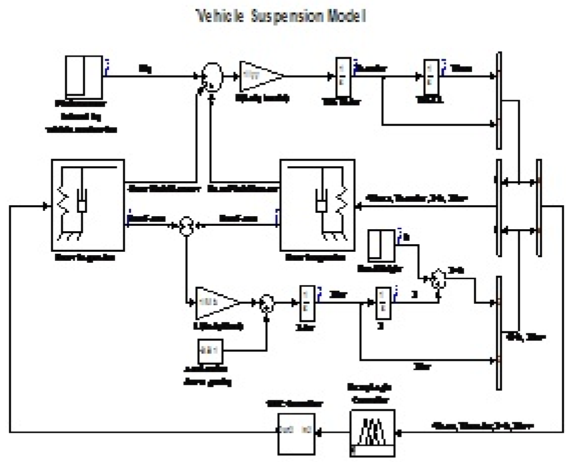

Fig: 14 Vehicle suspension model with SMC&FUZZY Controller

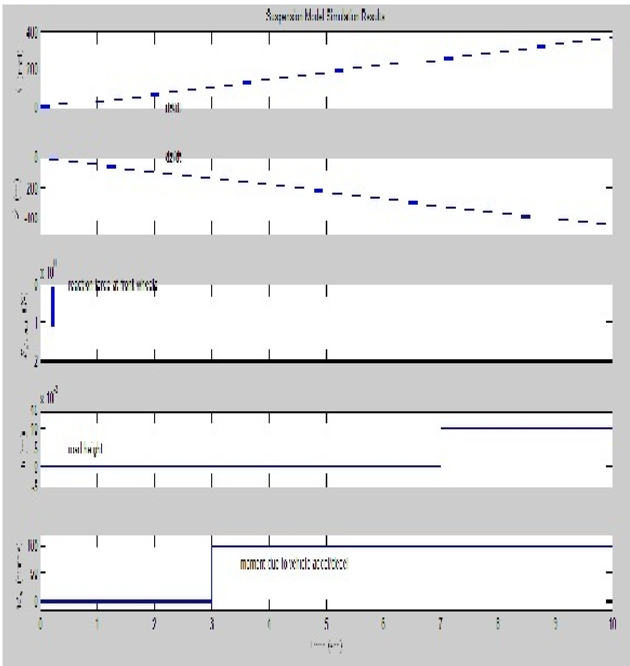

Fig: 15 Outputs for SMC & FUZZY LOGIC Controller

IV. CONCLUSION

In this paper, adaptive fuzzy logic controller was presented. The main characteristic of this architecture is the fuzzy controller's ability to accept new rule base, and membership functions during runtime without causing any undesirable behaviour to the plant. The proposed fuzzy controller was used to enhance the performance of a vehicle suspension system, by generating the damping coefficient required by the variable damper in the semi-active suspension systems. Simulation results demonstrated the controller's ability to stabilize a vehicles suspension system. During the course of the simulations, the controller's membership functions, and rule base were modified twice by the optimization block. Simulations demonstrated the controller's ability to adopt the new parameters in the control process without negatively affecting the response of the system.

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