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TWO RULES BASED FUZZY SWING-UP AND FOUR RULES BASED NONLINEAR FUZZY STABILIZATION OF ROTARY INVERTED PENDULUM AND COMPARISON WITH LINEAR FUZZY CONTROLLER AND LQR

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Abstract-**In this paper, Swing-up and Stabilization of the Rotary inverted pendulum (RIP) is done through the fuzzy controller.The attraction of this paper is achieving the above stated aim through lesser number of rules. RIP is highly unstable and nonlinear in nature, so stabilization of the RIP is itself a challenging task. Swing-up mechanism in RIP is a type of unstable mechanism which is done effectively by using a fuzzy controller only, by just two rules. There are four states of RIP that needs to be controlled and they are controlled by fuzzy controller with the help of only four rules.Simulation which is done on MATLAB/SIMULINK shows the effectiveness of the proposed controller and its implementation, successfully in real time.**
Keywords– Swing-up fuzzy, Stabilization fuzzy, RIP.

I. INTRODUCTION

The application of fuzzy control to large-scale complex systems is not, by no means, trouble-free. For such systems the number of the fuzzy IF-THEN rules as the number of sensory variables, increases very quickly to an unmanageable level. When we take into account more input variables in control system, the number of rules grows exponentially, if we have l possible values for each of n variables, we must describe control corresponding to all $\mathbf{l^n}$ possible combinations of input values. Here the method of sensory fusion is studied in an attempt to reduce the size of the inference engine for large-scale systems. This structure reduces the number of rules considerably [2]. But the adequate parameters should be estimatedfor the implementation of this technique. Much reliance has to be put on the experience of the operator tofind these parameters [3]. In this work we will find the estimation of the parameters of the sensory fusion method using LQR Mapping Based Information Fusion. It is an appropriate technique to find the parameters in a large search space. Also in the optimization problems it has shown efficient and reliable results [4][6].

II.4 RULE BASED FUZZY CONTROLLER

We can say that a fuzzy controller is linear or nonlinear on the basis of the control surface of FLC. If the control surface is like Fig.1 the FLC controller is said to be Non-linear. As there are some rippled type surface present in control surface, Nonlinearity handling capacity of FLC is due to this rippled surface. As the number of membership functions increase, the rippled structure of the control surface gets increased [1] ,in this way accuracy of the controller gets increased. But while increasing the number of membership functions the rule base of the FLC will getincreased. This would cause a rule explosion problem in FLC. So while one implement fuzzy controller on real time system, it might get into the saturation region because of the physical constraints of system. Thus when one designs a fuzzy controller for the real time problems these types of problems of the system must be considered.Therefore there should be a proper balance between the accuracy and rule base size,so that the physical implementation of the controller may be possible [1],[12].The nonlinear behavior of controller can also be seen through the Fig.2

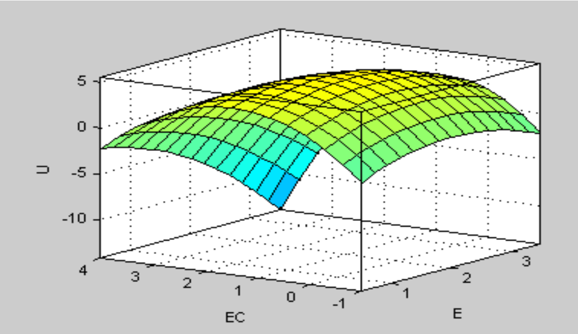

Fig.1Control surface of Non-linear FLC

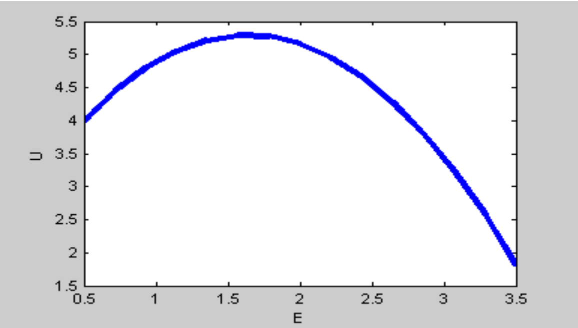

Fig.2 Nonlinear-relationship between the input and out of Non-linear FLC

Two fuzzy sets for the variable error E, change in error EC in universe of discourse of (-1 3.5) and (-2 4) and for control output U the universe of discourse (0 1).Defined membership functions are taken as a triangular for E and EC and linear for U.

Rules of fuzzy logic controller are taken as:

If E is 'N' and EC is 'N' then U is3.4E+4.1EC
If E is 'N' and EC is 'P' then U is 3.3E-.90EC
If E is 'P' and EC is 'N' then U is 0.3E+3.7EC
If E is 'P' and EC is 'P' then U is 0.5E-4.0EC

Where, U is the output of the T-S FLC corresponding to the above rules for input variables E and EC.

As this Nonlinear FLC have less number of rules than Linear FLC and still the accuracy of the Nonlinear FLC is good in terms of overshoots, settling time, parameter variation of plant etc.

III. SWING-UP CONTROLLER OF ROTARY INVERTED PENDULUM BY FUZZY LOGIC CONTROLLER

While examining the real time behavior of the Rotary Inverted Pendulum it was found that RIP rotates in clockwise, anticlockwise direction and remains stable at equilibrium position. Membership functions can be taken as positive, zero and negative but the formulation of rule base was very difficult if one considers the zero membership function because RIP remains at zero position for very short time. So to get rid of this problem we have given an initial disturbance to RIP so that it never remains in zero position. Thus membership functions will be either positive or negative as shown in Fig.3 .Thus decision making about the rule base of problem would be easy. Swing-up fuzzy controller has just one input and one output. The input to the fuzzy controller is velocity of the RIP.

Rule base of the controller is:

- *If input is N then output is N*
- *If input is P then output is P*

Just two rules are sufficient to swing the RIP from its stable position. It can be seen from the Fig. 4 that control signal would either be positive or negative. In this way for the positive input, the control signal will be positive and for negative input, control signal will be negative. In this way the energy is pumped in such a fashion that the RIP follows the above mentioned rules. Thus in this manner the RIP goes from pedant state to un-stable equilibrium position.

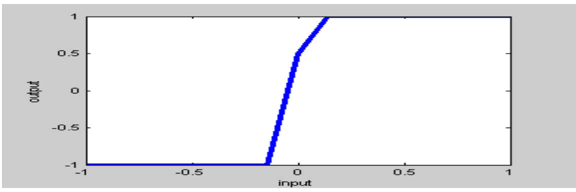

Fig.3 Control surface of swing-up FLC

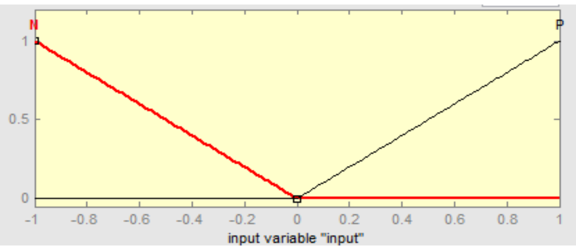

Fig.4 Membership functions for swing-up FLC

IV. CONTROL THEORY

As we know that RIP is highly nonlinear and unstable in nature with four states that needs to be stabilize, similarly RIP has two degrees of freedom.Thus it is tedious job to stabilize the Pendulum at vertical upright position. Although this is too difficult to stabilize RIP with fuzzy controller formulated by just four rules because of this four sates of RIP. But here we are presenting an approach to get this in simplified manner.LQR based sensory fusion[??] is used here to reduce the four sates of RIP into two states. In Fig. 5 Position(*x*) and Angle (*theta*) are fused into variable error (E) and Velocity (x_dot) and Angular velocity (theta_dot) are fused into change in error (EC)

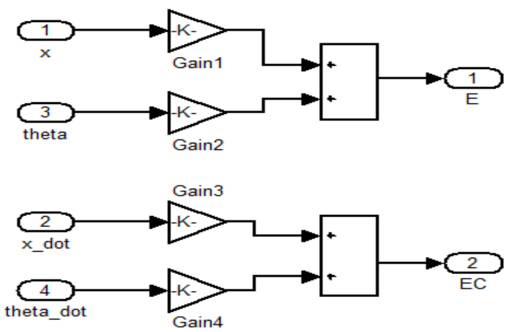

Fig. 5Fusion of the inputs of the rotary inverted pendulum

IV.SIMULATION AND RESULTS

The proposed technique is verified by simulation results of overall closed loop system. For the simulation purpose here three controllers are chosen and the controllers are LQR, linear fuzzy controller (nine rules based) and non-linear fuzzy controller (four rules based). Among all these controllers the non-linear fuzzy controller using just four rules is showing best results in terms of transient and steady state error of overall closed loop system.

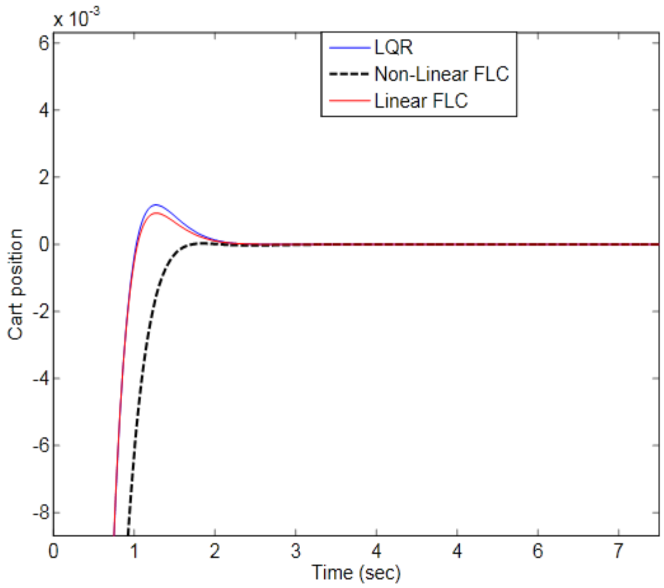

Fig.6 (a) Comparison between the LQR , Linear FLC, Non-Linear FLC for cart position

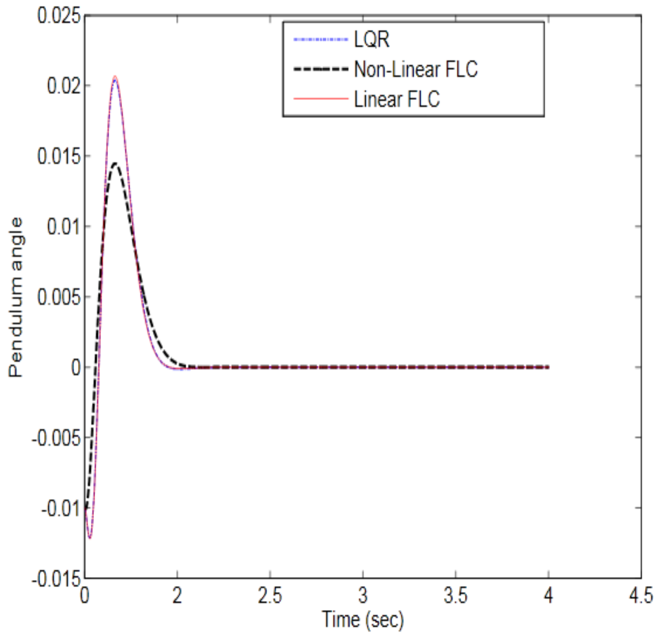

Fig.6 (b) Comparison between the LQR, Linear FLC, Non-Linear FLC for stabilization of IP

Fig.6 (a) & (b) shows that LQR controller has overshoots in comparison to fuzzy controller.

But Non-Linear FLC shows better response in comparison to Linear FLC. Settling time is almost same for all the three controllers.

In case of stabilization both the linear controller LQR and Linear FLC shows the same result. Both are superimposed on each other. On comparison of both linear and non-linear controllers, the latter shows better response in terms of overshoot. For the smooth operation of IP in real time there should not be large overshoots because it acts as a disturbance to IP. Fig.6 (b) shows Fuzzy controller is giving good result in comparison to LQR. This result shows the significance of fuzzy controllers over the LQR. In real time there are many noises, so fuzzy controller would be a good alternative over LQR. As LQR is a linear controller and in real time problems there are many non-linearities present in the system, these nonlinearities could be well handled by a nonlinear controller and one such nonlinear controller is Non-linear fuzzy controller. This argument can be proved through the result shown in Fig.6(b)

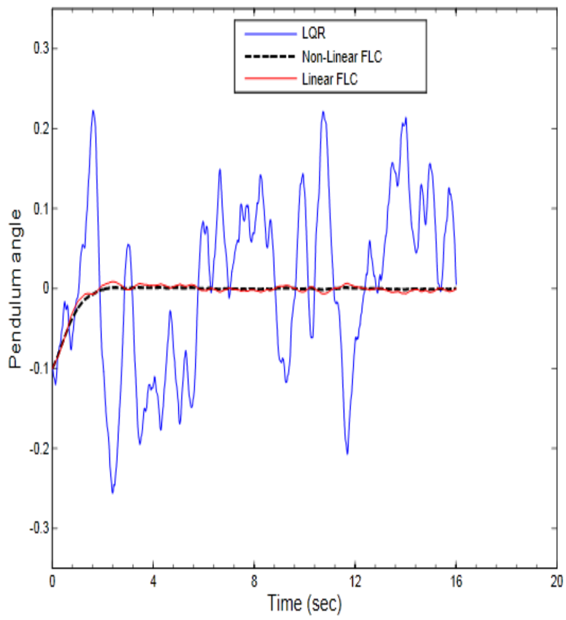

Fig.7 Comparison between the LQR, Linear FLC, Non-Linear FLC for stabilization of IP with external noise

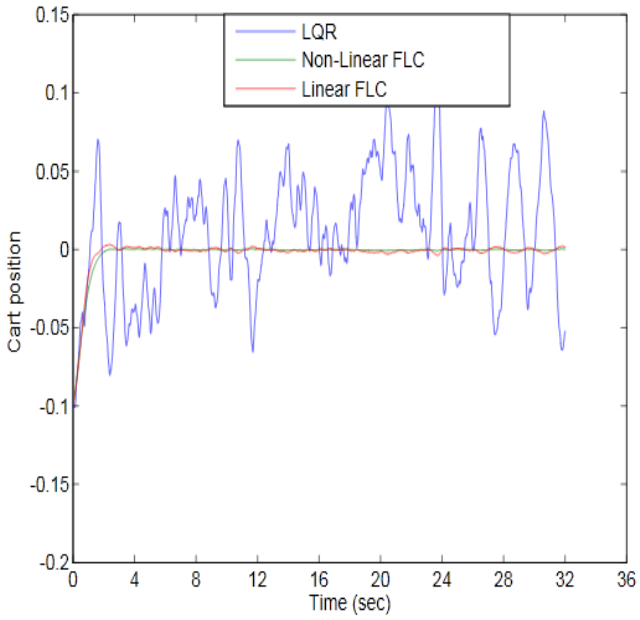

Fig.8 Comparison between the LQR, Linear FLC, Non-Linear FLC for cart position of IP with external noise

Fig.7 when external noise is added to control signal then the response of the LQR degrades as shown in Fig.7 and Fig.8 While the fuzzy controllers are showing better response than LQR because of its capability to handle uncertainties in comparison to LQR.

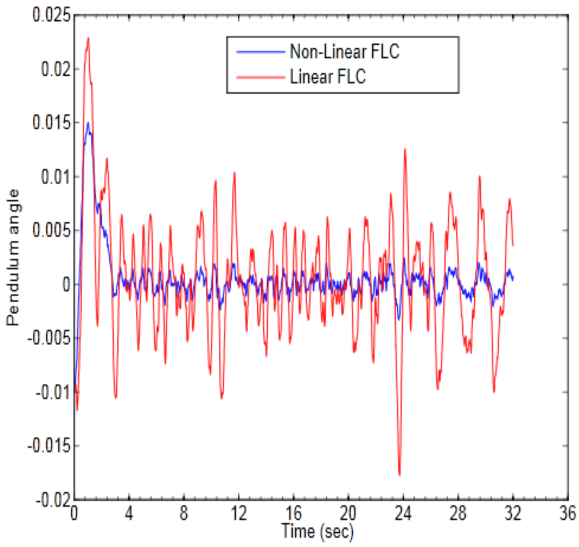

Fig.8 Comparison between the Linear FLC, Non-Linear FLC for stabilization of IP with external noise

Thus both Linear and Non-linear FLC have almost similar response for small power ofexternal noise but if noise power is increased by several folds, one observes a significant difference in between the responses of Linear and nonlinear FLC as seen in Fig.8Nonlinear FLC is showing better response than Linear FLC.

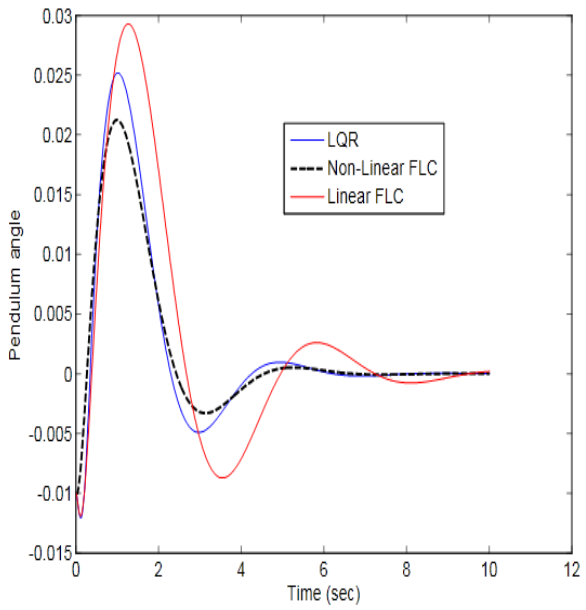

Fig.9 Comparison between the LQR Linear, Non-Linear FLC for stabilization of IP when beam length is doubled

Robustness property has been examined through Fig.9. When beam length is doubled, keeping rest of the parameters unchanged, all three controllers stabilize the IP.But the response of nonlinear FLC for the variation in beam length is around 50%, still better in comparison to Linear FLC and LQR.

VI.CONCLUSION

This paper concludes that the swing–up and stabilization of RIP at upright position has been done through the fuzzy controller with minimum number of rules. Fusion technique has been applied to reduce the number of inputs of the fuzzy controller so that the fuzzy controllers which have less number of rules can also be applied on complex systems. Non-linear fuzzy controller is showing better results compared to linear fuzzy controller and LQR as verified in simulation.It seems through the results that nonlinear controller is more effective as compared to linear controllers.

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