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Sliding Mode Controller Plus Fuzzy Logic Controller to Improve Performance of Negative Output Super Luo Converter

R. Thamaraiselvi[1]
Department of Electrical and Electronic Engineering,
Anna University- Villupuram Campus,
Tamilnadu, INDIA.
Email: r.thamaraiselvi75@gmail.com

Abstract:

This paper presents an approach to systematically design sliding mode control and manifold to stabilize nonlinear uncertain systems. It also deals with the fuzzy logic controller to increase the process of negative output converter. The objective is also accomplished to enlarge the inner bound of region of attraction for closed-loop dynamics. The method is proposed to design a control that guarantees both asymptotic and finite time stability given helped by (bilinear) sum of squares programming. The approach introduces an iterative algorithm to search over sliding mode manifold and Lyapunov function simultaneity. In the case of local stability it concludes also the subset of estimated region of attraction for reduced order sliding mode dynamics. The sliding mode manifold and the corresponding Lyapunov function are obtained if the iterative SOS optimization program has a solution. Results are demonstrated employing the method for several examples to show potential of the proposed technique.

keywords: *Sliding mode control, Finite time controller, Matched perturbation, Sum of squares, Lyapunov function, asymptotic, stability*.

1.Introduction

Sliding mode control is one of the most effective control methodologies in dealing with a large class of uncertain systems. The controller consists of a high-frequency switching term that completely compensates matched perturbations (i.e. perturbations acting in the direction of control input). [1] This action takes place when state trajectory remains on the subspace of the state space called “sliding manifold”. Much work has been done in the literature to define several sliding mode manifold; the linear sliding manifold is investigated for linear and nonlinear system in [2] nonlinear sliding manifold known as a “terminal sliding mode” also have been introduced in [3] to obtain finite time stability [6]; the problem of singularity of this type of sliding manifold is alleviated and thus “nonsingular terminal sliding mode” have been defined [5]; in order to increase the speed of reaching fast terminal sliding manifold is presented .

Several sliding mode manifold have been introduced by many articles[6], but selecting a sliding manifold, and determining its parameters is nevertheless an open problem in SMC theory, especially in the case that a complex nonlinear manifold is required. In some applications, linear sliding manifold fails to stabilize the sliding mode dynamics. Fuzzy logic can be conceptualized as a generalization of classical logic. Modernfuzzy logic was developed by LotfiZadeh in the mid-1960s to model thoseproblems in which imprecise data must be used or in which the rules of inferenceare formulated in a very general way making use of diffuse categories. In fuzzy logic, which is also sometimes called diffuse logic, there are notjust two alternatives but a whole continuum of truth values for logical propositions.A proposition *A* can have the truth value 0.4 and its complement *Ac* the truth value 0.5. According to the type of negation operator that is used,the two truth values must not be necessarily add up to 1.

This paper presents a systematic approach utilizing SOS technique, an approach based on Semi-definite programming to deal with polynomial systems to obtain sliding mode controller. The approach involves iterative search over sliding manifold and lyapunov function. The proposed method contains SOS optimization program that determine sliding manifold and controller to enlarge the inner bound of region of attraction for the sliding mode dynamics, in case of local stability. Since, pragmatic engineering applications requires finite time stability rather than asymptotic stability, we extend our results to these cases. We introduce a general framework to obtain sliding manifold that ensures finite time stability for sliding mode dynamics. This approach contains all types of terminal sliding mode which are proposed in several papers.

2. Classical Sliding Mode Control

Consider the following uncertain dynamical system

$\dot{x}(t) = Ax(t)+Bu(t)+ f(t;x;u)$

$$y(t) = Cx(t) \quad (1)$$

where $x \in \mathrm{IR}^n$, $u \in \mathrm{IR}^m$ and $y \in \mathrm{IR}^p$ with $m \leq p \leq n$ represent the usual state, input and output. The exposition is deliberately formulated as an output feedback problem in order to describe the constraints imposed by the availability of limited state information but the analysis collapses to state feedback when C is chosen as the identity matrix. Assume that the nominal linear system $(A;B;C)$ is known and that the input and output matrices B and C are both of full rank. The system nonlinearities and model uncertainties are represented by the unknown function $f : \mathrm{IR}_+ \times \mathrm{IR}^n \times \mathrm{IR}^m \rightarrow \mathrm{IR}^n$, which is assumed to satisfy the matching condition whereby

$$f(t;x;u) = B\xi(t;x;u) \quad (2)$$

The bounded function $\xi : \mathrm{IR}_+ \times \mathrm{IR}^n \times \mathrm{IR}^m \rightarrow \mathrm{IR}^m$ satisfies for some known function $\alpha : \mathrm{IR}_+ \times \mathrm{IR}^p \rightarrow \mathrm{IR}_+$ and positive constant $k_1 < 1$. The intention is to develop a control law which induces an ideal sliding motion on the surface for some selected matrix $F \in \mathrm{IR}^{m \times p}$. A control law comprising linear and discontinuous feedback is sought

$$\|\xi(t;x;u)\| < k_1\|u\| + \alpha(t;y) \quad (3)$$

$$S = \{x \in \mathrm{IR}^n : FCx = 0\} \quad (4)$$

$$u(t) = -Gy(t) - \nu_y \quad (5)$$

where G is a fixed gain matrix and the discontinuous vector is given by

$$\nu_y = \begin{cases} \rho(t;y)\dfrac{Fy(t)}{\|Fy(t)\|} & \text{if } Fy \neq 0 \\ 0 & \text{otherwise} \end{cases} \quad (6)$$

where $\rho(t;y)$ is some positive scalar function. The motivating example presented in Section I clearly demonstrates that two systems with different dynamics, the double integrator and the scaled pendulum, exhibit the same first order dynamics when in the sliding mode. It is thus intuitively obvious that the effective control action experienced by what are two different plants must be different. The so-called *equivalent control* represents this effective control action which is necessary to maintain the ideal sliding motion on S. The equivalent control action is not the control action applied to the plant but can be thought of as representing, on average, the effect of the applied discontinuous control. Fig 1 illustrates the phase control system in sliding mode. To explore the concept of the equivalent control more formally, consider equation (5) and suppose at time t_s the systems states lie on the surface S defined in (8). It is assumed an ideal sliding motion takes place so that $FCx(t) = 0$ and $\dot{s}(t) = FC\dot{x}(t) = 0$ for all $t \geq t_s$. Substituting for $\dot{x}(t)$

$$x(t) = FCAx(t)+FCBu(t)+FC f(t;x;u) = 0 \quad (7)$$

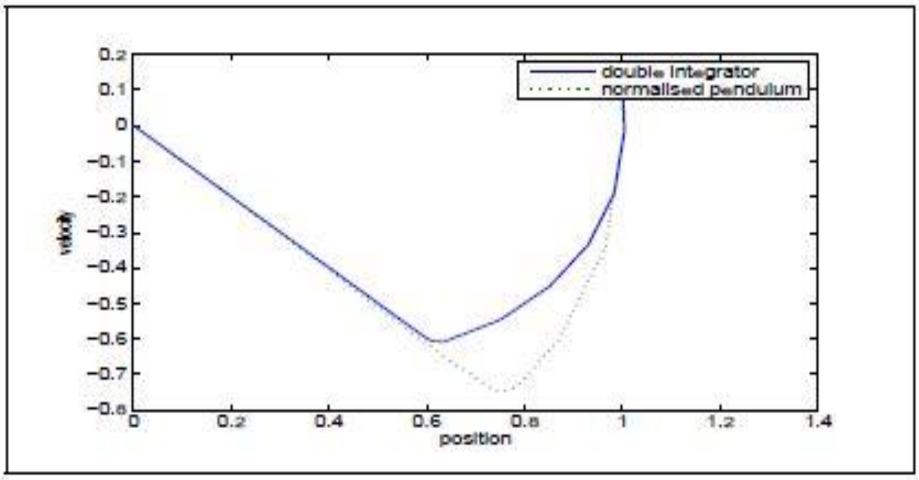

Fig. 1: Phase plane portrait showing the response of the double integrator ($a1 = 0$) and the scaled pendulum system ($a1 = 1$) with initial conditions $y(0) = 1; \dot{y}(0) = 0:1$

Figure 2 shows a plot of $0:1\sin(t)$ in relation tothe smooth control signal applied to the plant. It is seen that the applied (smooth) control signal replicates very closely the applied perturbation, even though the control signal is not constructed with a priori knowledge of the perturbation. This property has resulted in great interest in the use of sliding mode approaches for condition monitoring and faultdetection . A key feature of the sliding mode control approach is the ability to specify desired plant dynamics by choice of the switching function. Whilst sliding $s = FCx= 0$ for all $t > t_s$and it follows that exactly m of the states can be expressed in terms of the remaining $n-m$. It can be shown that the matrix (13) defining the equivalent system dynamics has at most $n-m$ nonzero eigenvalues and these are the poles of the reduced order dynamics in the sliding mode.

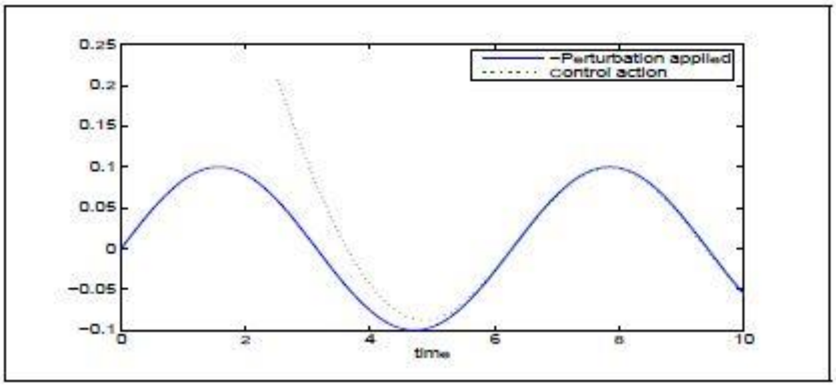

Fig. 2: The relationship between the smooth control signal applied and the external perturbation once the sliding mode is reached

3. The fuzzy set concept:

Fuzzy logic can be used as an interpretation model for the properties ofneural networks, as well as for giving a more precise description of their performance.[7,8]We will show that fuzzy operators can be conceived as generalized output functions of computing units. Fuzzy logic can also be used to specify networks directly without having to apply a learning algorithm. An expert in a certain field can sometimes produce a simple set of control rules for a dynamical system with less effort than the work involved in training a neural network. A classic example proposed by Zadeh to the neural network community is developing a system to park a car. It is straightforward to formulate a set of fuzzy rules for this task, but it is not immediately obvious how to build a network to do the same nor how to train it. Fuzzy logic is now being used in many products of industrial and consumer electronics for whicha *good* control system is sufficient and where the question of *optimal* control does not necessarily arises.[9]

The difference between crisp (i.e., classical) and fuzzy sets is established byintroducing a *membership function*. Consider a finite set $X = \{x1, x2, \dots, xn\}$which will be considered the universal set in what follows. The subset A of X consisting of the single element $x1$ can be described by the n-dimensional membership vector $Z(A) = (1, 0, 0, \dots, 0)$, where the convention has been adopted that a 1 at the i-th position indicates that xi belongs to A. The set$B$ composed of the elements $x1$ and $xn$is described by the vector $Z(B) = (1, 0, 0, ..., 1)$. Any other crisp subset of X can be represented in the same way by an n-dimensional binary vector. But what happens if we lift the restriction to binary vectors? In that case we can define the *fuzzy set C* with the following vector description:

$Z(C) = (0.5, 0, 0, ...,0)$ (8)

In classical set theory such a set cannot be defined. An element belongs to a subset or it does not. In the theory of fuzzy sets we make a generalization and allow descriptions of this type. In our example the element $x1$ belongs to the set C only to some extent.

Figure 3 shows three examples of a membership function in the interval0 to 70 years. The three functions define the degree of membership of any given age in the sets of young, adult, and old ages.[10] If someone is 20 years old, for example, his degree of membership in the set of young persons is 1.0, in the set of adults 0.35, and in the set of old persons 0.0. If someone is 50 years old the degrees of membership are 0.0, 1.0, 0.3 in the respective sets. Figure 3 illustrates the Membership functions for the concepts young, mature and old

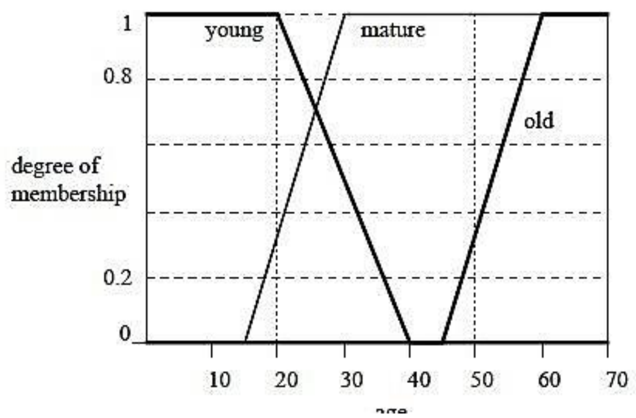

Fig. 3.Membership functions for the concepts young, mature and old

4. Canonical form for design:

This section will consider synthesis of a sliding mode control for the system in . It is assumed that $p \geq m$and rank$(CB) = m$ where the rank restriction is required for existence of a unique equivalent control. The first problem which must be considered is how to choose F so that the associated sliding motion is stable. A control law will then be defined to guarantee the existence of a sliding motion [11].

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4.1. Switching Function Design

In view of the fact that the outputs will be considered, it is first convenient to introduce a coordinate transformation to make the last p states of the system the outputs. Define

Tc= [NTcC] (9)

whereNc∈IRn×(n−p) and its columns span the null space of C. The coordinate transformation x 7→ $Tcx$is nonsingular by construction and, as a result, in the new coordinate system

C = [0Ip] (10)

From this starting point a special case of the so-called regular form defined for the state feedback case [14] will be established. Suppose

B = [Bc1Bc2] ↕n−p↕p(11)

Then CB = Bc2 and so by assumption rank(Bc2) = m. Hence the left pseudo-inverse

B†c2 = (BTc2Bc2)−1BTc(12)

2 is well defined and there exists an orthogonal matrix T ∈IRp×$p$such that

TTBc2 = [0B2] (13)

where$B$2 ∈IRm×$m$is nonsingular. Consequently, the coordinate transformation x 7→ $Tbx$where Tb =[In−p −Bc1B†c2 0 TT] (14)

isnonsingular and the triple (A;B;C) is in the form A = [A11 A12 A21 A22] B = [0 B2] C =[0 T] (15)

where$A$11 ∈IR(n−m)×(n−m) and the remaining sub-blocks in the system matrix are partitioned accordingly. Let p−m ↔ m↔[F1 F2] = FT

where$T$ is the matrix from equation. As a result FC = [F1C1F2] (16)

where$C$1 ∆= [0(p−m)×(n−p) I(p−m)] (17)

Therefore FCB=F2B2 and the square matrix F2 is nonsingular. By assumption the uncertainty is matched and thereforethe sliding motion is independent of the uncertainty.

5. Geometric representation of fuzzy sets:

Bart Kosko introduced a very useful graphical representation of fuzzy sets. Figure 11.2 shows an example in which the universal set consists only of the two elements x1 and x2. Crisp sets are a special case of fuzzy sets, since the range of the functionis restricted to the values 0 and 1. Operations defined over crisp sets, such as union or intersection, can be generalized to cover also fuzzy sets. [12]Assume as an example that X = {x1, x2, x3}. The classical subsets A = {x1, x2} and B = {x2, x3} can be represented as A = 1/x1 + 1/x2 + 0/x3 B = 0/x1 + 1/x2 + 1/x3.The union of A and B is computed by taking for each element xi the maximumof its membership in both sets, that is: A ∪B = 1/x1 + 1/x2 + 1/x3. The *fuzzy union* of two fuzzy sets can be computed in the same way. The union of the two fuzzy sets C = 0.5/x1 + 0.6/x2 + 0.3/x3 D = 0.7/x1 + 0.2/x2 + 0.8/x3 is given by C ∪D = 0.7/x1 + 0.6/x2 + 0.8/x3

The fuzzy intersection of two sets A and B can be defined in a similar way, but instead of taking the maximum we compute the minimum of the membership of each element xi to A and B. The maximum or minimum of the membership values are just one pair of possible definitions of the union and intersection operations for fuzzy sets. As we show later on, there are other alternative definitions[13]. The Geometric visualization of fuzzy sets was shown in the figure 4.

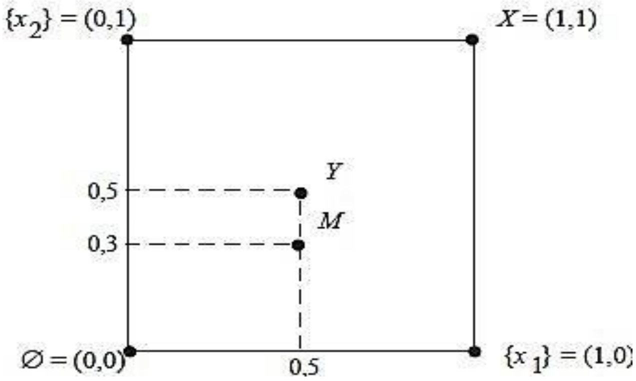

Fig. 4 Geometric visualization of fuzzy sets

6. Sliding Mode Equations:

So far the arguments in favor of employing sliding modes in control systems have been discussed at the qualitative level. To justify them strictly, the mathematical methods should be developed for describing this motion in the intersection of discontinuitysurfaces and deriving the conditions for sliding mode to exist.[14]The first problem means deriving differential equations of sliding mode. Note that for our second-order example the equation of the switching line *x*+ *cx* = 0 was interpreted as the motion equation. But even for a time invariant second-order relay system. 1 111 12 2 1 2 21 1 22 2 2 , 1 2; , *ij*, *i* , are *x a x a x bux a x a x b u uMsign s s cx x M a b c const*= + += + + =− = +. the problem does not look trivial since in sliding mode *s* = 0 is not a motion equation. *Ts x = s x = s x sm x.*

The first problem arises due to discontinuities in control, since the relevant motion equations do not satisfy the conventional theorems on existence-uniqueness of solutions. In situations when conventional methods are not applicable, the usual approach is to employ regularization or replacing the initial problem by a closely similar one, for which familiar methods can be used. In particular, taking into account delay or hysteresis of a switching element, small time constants in an ideal model, replacing a discontinuous function by a continuous approximation are examples of regularization since discontinuity points (if they exist) are isolated. The universal approach to regularization consists of introducing a boundary layer $s < \Delta$, Δ − *const*around the manifold $s = 0$, where an ideal discontinuous control is replaced by a real one such that the state trajectories are not confined to this manifold but run arbitrarily inside the layer The only assumption for this motion is that the solution exists in the conventional sense. Fig.5 illustrates the boundary layer

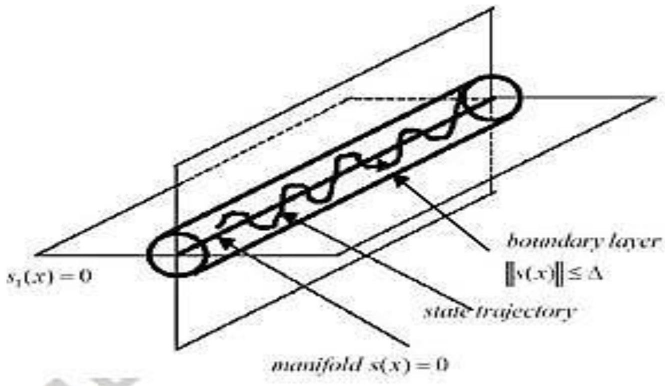

Figure 5. Boundary layer

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7. Neuro-fuzzy systems:

Neuro-fuzzy systems were introduced in the thesis of Jyh-Shing Roger Jang in 1992 under the name “Adaptative-Networks-based Fuzzy Inference Systems" (ANFIS) . They use the formalism of neural networks by expressing the structure of a fuzzy system in the form of a multilayer perceptron. A multilayer perceptron (MLP) is a neural network without cycle. [15]The input layer is given a vector network and the network returns a result vector in the output layer.[16-18]Between these two layers, the elements of the input vector are weighted by the weights of the connections and mixed in the hidden neurons located in the hidden layer.[19] Figure 6 and 7illustrates an example of a feedforward neural network and structure of fuzzy neural network.

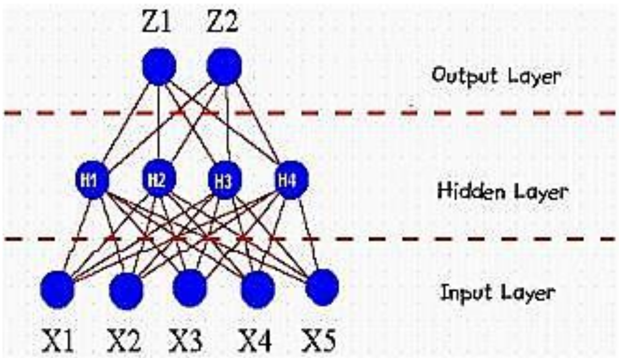

Figure 6: Example of a feed forward neural network

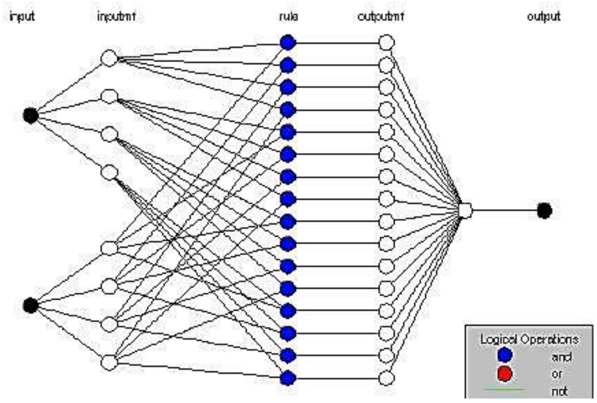

Figure 7: Structure of a neuro-fuzzy system

8. Conclusion:

This paper presents an approach to systematically design sliding mode control and manifold to stabilize nonlinear uncertain systems. It also deals with the fuzzy logic controller to increase the process of negative output converter. The objective is also accomplished to enlarge the inner bound of region of attraction for closed-loop dynamics. The method is proposed to design a control that guarantees both asymptotic and finite time stability given helped by (bilinear) sum of squares programming. The approach introduces an iterative algorithm to search over sliding mode manifold and Lyapunov function simultaneity. In the case of local stability it concludes also the subset of estimated region of attraction for reduced order sliding mode dynamics. The sliding mode manifold and the corresponding Lyapunov function are obtained if the iterative SOS optimization program has a solution. Results are

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Reference:

[1] Kumar, K. Ramash, S. Jeevananthan, and S. Ramamurthy. "Improved performance of the positive output elementary split inductor-type boost converter using sliding mode controller plus fuzzy logic controller." WSEAS Transactions on Systems and Control 9 (2014): 215-228.
[2] Abjadi, Navid. "Design and implementation of a constant frequency sliding mode controller for a Luo converter." International Journal of Engineering 29.2 (2016): 202-210.
[3] Muthukaruppasamy, S., "Design and Implementation of Sliding Mode Controller Plus Fuzzy Logic Controller for Discontinuous Conduction Mode Operation of Negative Output Elementary Super Lift Luo Converter." Journal of Computational and Theoretical Nanoscience 13.11 (2016): 8505-8521.
[4] Abudhahir., et al. "Design and implementation of PIC/FLC plus SMC for positive output elementary super lift luo converter working in discontinuous conduction mode." Journal of Electrical Engineering and Technology 13.5 (2018): 1886-1900.
[5] Abraham, Steffin, TanaLuciyaJoji, and D. Yuvaraj. "Enhancing vehicle safety with drowsiness detection and collision avoidance." International Journal of Pure and Applied Mathematics 120.6 (2018): 2295-2310.
[6] N. Arunkumar, and T. S. Sivakumaran. "Implementation of Non-Linear Controller for Contemporary DC-DC Converter." International Journal on Electrical Engineering and Informatics 11.4 (2019): 622-637.
[7] Amudha, A., et al. "Modeling, Simulation and Design of Luo Converter for DC Micro Grid Application." 2020 Fourth International Conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud)(I-SMAC). IEEE, 2020.
[8] Selvan, S. Sentamil, K. Ramash Kumar, and R. Bensraj. "Modeling, simulation and design of variable structure based sliding mode controller for KY-voltage boosting converter." WSEAS Trans. Circuits Syst 15 (2016): 143-154.
[9] Veeranna, G., K. Vaisakh, and R. SrinivasRao. "Matlab/simulink study of effective controller for discrete speed pfc super lift converter fed bldc motor drive." Journal of Critical Reviews 7.12 (2020): 437-444.
[10] Deng, Huiwen, et al. "High-order sliding mode observer based OER control for PEM fuel cell air-feed system." IEEE Transactions on Energy Conversion 33.1 (2017): 232-244.
[11] Ramash Kumar, K. "FLC and PWM SMC for KY boost converter." Journal of Circuits, Systems and Computers 28.11 (2019): 1950184.
[12] Venkatramanan, C. B., and S. Padma. "Automatic power factor and speed control of three phase induction motor using programmable logic control." International Journal of Engineering & Technology 7.2.8 (2018): 533-538.
[13] Nandhagopal, N., S. Navaneethan, and C. Arul Murugan. "The reordered deblocking filter and SAO architecture for HEVC system." International Journal of Engineering & Technology 7.2.8 (2018): 617-621.
[14] MohdZaihidee, Fardila, SaadMekhilef, and MarizanMubin. "Robust speed control of PMSM using sliding mode control (SMC)—A review." Energies 12.9 (2019): 1669.
[15] Deng, Huiwen, et al. "Nonlinear controller design based on cascade adaptive sliding mode control for PEM fuel cell air supply systems." International Journal of Hydrogen Energy 44.35 (2019): 19357-19369.
[16] Geetha, K., et al. "Detection and monitoring of fire and gas leakage systems in industries." International Journal of Engineering & Technology 7.2.8 (2018): 419-423.
[17] Sankar, VV Arun, AP ArunPravin, and P. Suresh. "Load and Emission Characteristics of PongamiaPinnata Oil in ACI Engine." International Journal of Engineering & Technology 7.2.24 (2018): 518-526.
[18] Prathap, Joseph Anthony, et al. "Performance evaluation and analysis of 64-quadrature amplitude modulator using Xilinx Spartan FPGA." International Journal of Engineering & Technology 7.2.8 (2018): 570-577.
[19] Krishnan, S. Navaneetha, P. SundaraVadivel, and D. Yuvaraj. "An Effective Document Category Prediction System Using Support Vector Machines, Mann-Whitney Techniques." International Journal of Pure and Applied Mathematics 120.6 (2018): 2267-2282.

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