# Fuzzy-Driven Sliding Mode Control for Nonlinear Biomedical Systems: A Stability and Safety Approach

**B. Balajee [1], M. Dinesh Kumar [2], U. Mohamed Yasin [3], A P. Mohammed Siyad [4],**

M . Yasar Arabhath [5], E S. Bharathkumar [6]

[1,2]Assistant Professor, [3, 4, 5, 6]Final Year B.E. EEE
Department of Electrical and Electronics Engineering
Al-Ameen Engineering College (Autonomous)
Erode–638 104, Tamilnadu, India.

*Abstract*:
This study presents a novel approach for designing sliding-mode control and manifold structures to stabilize nonlinear and unpredictable biomedical systems, with applications in physiological signal regulation, robotic-assisted surgery, and adaptive drug delivery. A fuzzy controller is integrated to accelerate the negative input conversion process, enhancing real-time adaptability in dynamic medical environments. The proposed method expands the inner stability region for closed-loop kinetics, ensuring robust system behavior under uncertainty. Using bilinear mean square computation, a control mechanism is developed to guarantee both ergodicity and finite-time safety, crucial for medical applications requiring precise and stable operation. An iterative search strategy is employed within the sliding mode manifold, synchronizing it with a Lyapunov function for stability verification. Furthermore, a sum-of-squares (SOS) optimization program is utilized to generate the variable structure manifold and its corresponding Lyapunov function, ensuring local stability in lower-order nonlinear biomedical kinetics. The efficacy of the proposed approach is demonstrated through multiple case studies, highlighting its potential for enhancing the reliability and safety of biomedical control systems.
KEYWORDS—Finite time controller,Sliding mode control, Sum of squares, Matched perturbation, asymptotic, Lyapunov function,

## 1. INTRODUCTION

Linear control was the most successful control strategies for a wide range of unstable systems. A fast switching term in the controller completely accommodates matched disturbances. [1] This action occurs when the state path remains in the "slide manifold" region of the state vector. Much work was done in the literary works to define numerous sliding mode manifolds; the linear sliding pipe was already explored for nonlinear and linear systems in [2], and a nonlinear sliding manifold recognised as a "end sliding method" has been presented in [3] to acquire finite amount of time stability [6]; the issue of infinite of this sort of sliding manifold was already assuaged, and thus "nonsingular transit sliding method" has now been characterised [5].

Many articles[6] have presented many gliding mode manifolds, but picking a sliding manifolds and calculating its parameters remains an open topic in SMC theory, especially when a complicated nonlinear surface is needed. The linear gliding manifold fails to stabilise the variable structure dynamics in various situations. Classical logic can be thought of as an extension of fuzzy logic. Lotfi Zadeh created modern fuzzification in the mid-1960s to represent scenarios in which inaccurate data should be used or infer rules should be defined in a highly general way using diffuse concepts. There are not simply two options in fuzzy logic, that is also known as diffuse logic. Instead, there is a full spectrum of truth.

This study describes a systematic approach to obtaining a sliding mode controller using the SOS technique, which is centered on Semi-definite coding to deal with algebraic systems. Iterative scanning over a sliding surface and the lyapunov value is used in this method. In the case of limited stability, the proposed solution includes an SOS optimization programme to determine the sliding band and a controller to extend the inner bound of the zone of attraction for nonlinear adaptive dynamics. We extend our findings to these circumstances since pragmatic applications of this technology demand finite temporal stability rather than hyperbolic stability. We present a general approach for obtaining a sliding manifold that assures sliding mode fluctuations are stable in finite time.

## 2. CONTROL FOR THE CLASSICAL SLIDING MODE

Assume the unknown system model below:

$$x(t) = Ax(t)+Bu(t)+ f(t;x;u)$$

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

where x IRn, u IRm, and y IRp indicate the normal state, output, and result, and m p n represents the usual state, insight, and outcome. The analysis reduces to feedback linearization when C was selected as the exact solution, however the exposition is purposefully framed as a feedback control problem to highlight the limits imposed by the existence of restricted state information. Suppose that the basic linear combination (A;B;C) is given, and that the B and C source and destination factorization are both extensive. The function f f: IR+IRnIRm IRn, that is believed to meet the matching criterion, represents the system non - linearities and parameter uncertainties.

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

$\|\xi(t;x;u)\| < k1\|u\| + \alpha(t;y)$ (3)

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

$u(t) = -Gy(t) - \nu y$ (5)

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

$\nu y = \{\rho(t;y)\ Fy(t)\ \|Fy(t)\|$ if $Fy \neq 0$ 0 otherwise (6)

where (t;y) represents a scalar function that is positive. When the dual integrator and the scaling pendulum are in the sliding surface, the inspiring example described in Section I clearly indicates that two subsystems with different consequences, the double integration and the scale oscillation, show the same first order dynamic behaviour. As a result, it should be self-evident that the proper control action perceived by the two crops is distinct. This effective control action is represented by the so-called comparable control, which is required to preserve the ideal downward direction on S. The comparable type of control is not the management action given to the plant, but it can be regarded of as the consequence of the imposed discontinuous command on average. The amplitude control scheme in variable structure is shown in Fig 1.

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

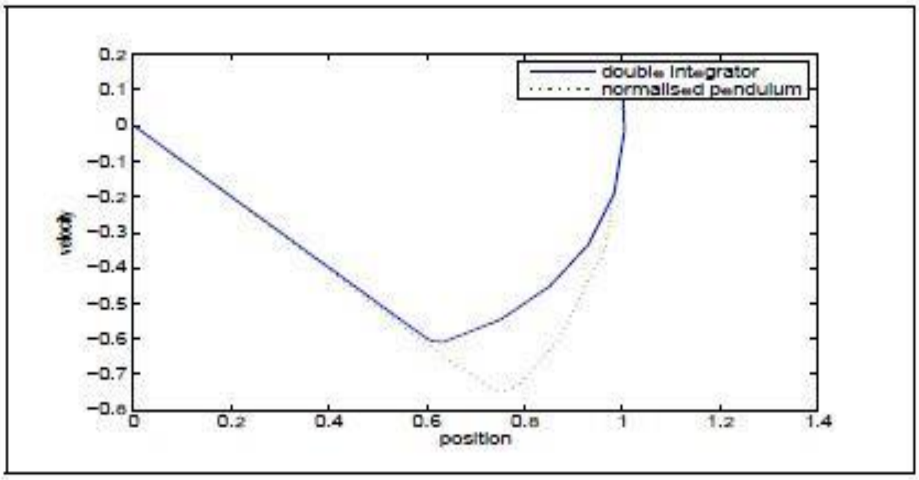

**Fig. 1: With beginning conditions, a phase space picture of the reaction of the double aggregator and the scaled swing system is shown.**

A plot of 0:1sin(t) in relationship to the designed control input supplied to the plant is shown in Figure 2. Even though the operating point is not produced with a prior information of the disturbance, it can be shown that the transmitted (smooth) controller output nearly duplicates the perturbation. The employment of sliding mode techniques for monitoring systems and defect detection has sparked a lot of attention because of this property. The capacity to specify optimal plant characteristics by choosing the switching mechanism is a significant element of the linear control strategy..

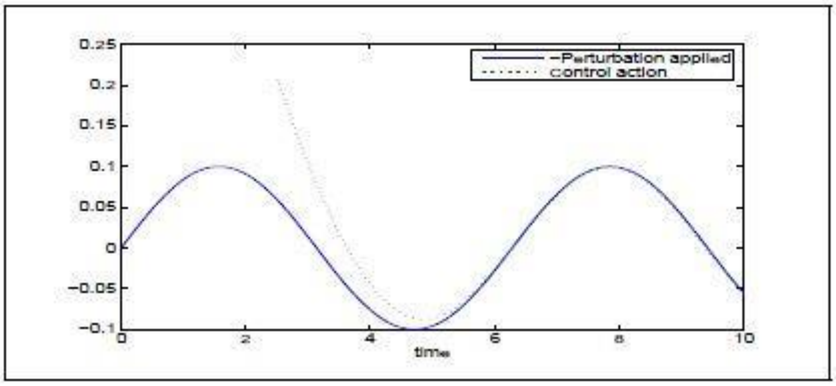


**Fig. 2: Once the sliding mode is attained, the relationship between the continuous control signal supplied and the external disturbance**

### 3. The fuzzy set concept:

Fuzzy logic could be utilised as an interpretive model for artificial neural properties and a more exact explanation of their function. [7,8] Fuzzy agents can be thought of as generalised basis function of computing machines, as we will illustrate. Without using a learning technique, fuzzy logic could be utilised to specify networks explicitly. With less work than machine learning, an expertise in a particular field sometimes can generate a basic number of control rules for a stochastic process.Zadeh gave the neural net community a famous example of designing a system to park an automobile. It is simple to create a fuzzy rule for this activity, but it is not entirely apparent how to develop and train a system to do so as well.

Fuzzy logic is increasingly being employed in a wide range of consumer and industrial electronics goods where a good management system is adequate and optimum control is not required. [9]

By providing a membership function, the distinction between crisp (i.e., classical) and fuzzy systems is defined. Consider the limited set X = x1, x2,..., xn, that will be referred to as the global set in the following discussion. The n-dimensional membership matrix Z(A) = (1, 0, 0,.., 0) can be used to express the subset A of X comprising of the monopole x1, where the standard is that a 1 at the i-th point signifies that xi is to A. The vector Z(B) = describes the set B, which consists of the components x1 and xn (1, 0, 0, ..., 1). An e s binary column can describe any other compact subset of X in same way. But what if we don't limit ourselves to binary?

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

Figure 3 depicts three membership functions in the age range of 0 to 70 years. The three factors define the degree to which a given age belongs to the groups of youthful, mature, and elderly. [10] For instance, when someone was 20 years old, his membership degree in the set of young folks is 1.0, 0.35 in the set of adults, and 0.0 in the set of elderly people. The degrees of participation in the three sets for someone 50 years old are 0.0, 1.0, and 0.3. The Corresponding membership for the notions young, adult, and elderly are shown in Figure 3.

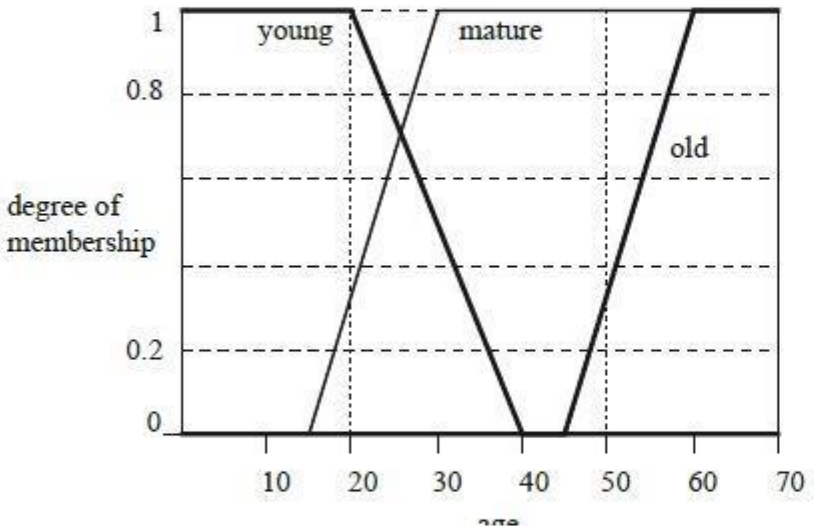


**Fig. 3. The concepts of young, mature, and old all have membership purposes.**

## 4. CANONICAL DESIGN FORMAT:

The formulation of a control scheme for the system in will be discussed in this section. The rank constraint is essential for the presence of a distinct equivalent control, therefore p m and rank(CB) = m are assumed. The first issue to tackle is how to select F in such a way that the accompanying sliding movement is stable. The existence of a flow path will therefore be guaranteed by a control law. [11]

### *4.1. Design ofSwitching Function*

Because the outputs will be examined, it is first necessary to apply a coordinate conversion to convert the system's latest p states to outcomes. Define

$$T_c = [\, N^T_c \; C \,] \qquad (9)$$

The null universe of C is spanned by Nc IRn(np) and its rows. By definition, the coordinate transformation x 7 Tcx is non-singular, and as a consequence, the new reference frame is non-singular.

$$C = [\; 0 \;\; I_p \;] \qquad (10)$$

## 5.Fuzzy sets

Bart Kosko devised a graphical depiction of fuzzy sets that is quite useful. Figure 11.2 presents an example where the universal set is made up of only two components, x1 and x2. Crisp settings are a subset of fuzzy sets in which the function's range is limited to the numbers 0 and 1. Union and intersection operations, which are specified for crisp sets, can be generalised to include fuzzy sets as well. [12] Consider the case where X = x1, x2, and x3. A = x1, x2 and B = x2, x3 are two classical subsets that can be expressed. The combination of A and B is calculated by taking the greatest of an element's participation in both sets for each xi.

In a similar fashion, the fuzzy overlap of two pairs A and B may be defined, but instead of selecting the maximum, we calculate the minimum of every element xi's inclusion in A and B. One pair of alternative criteria for the union and overlap procedures for fuzzy sets is the greatest or lowest of the membership functions. Other interpretations are possible, as we will see later. [13]. Figure 4 depicts the geometric depiction of fuzzy sets.

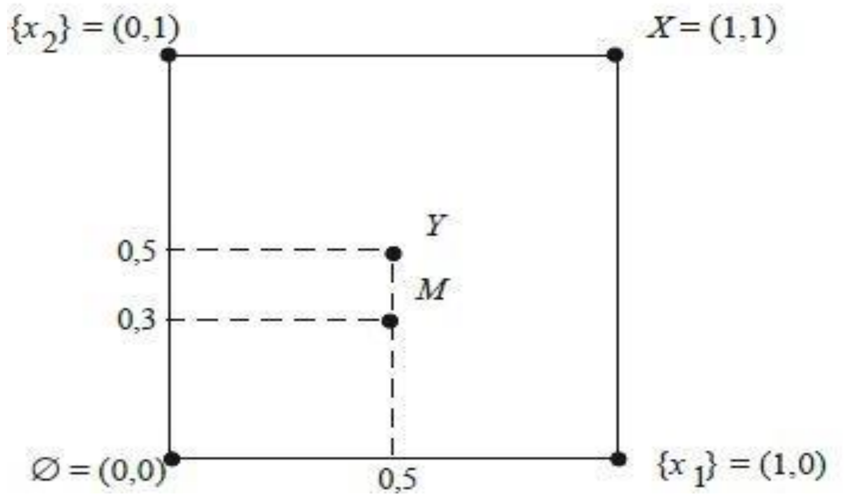


**Fig. 4 Fuzzy sets shown geometrically**

**6. Equations for Sliding Mode:**

The arguments for using sliding phases in controllers have so far been examined on a critical look. To properly justify them, theoretical methods for characterising this motion at the junction of irregularity surfaces and determining the requirements for variable structure to exist must be devised. [14] The first challenge entails deriving backstepping system of equations. The equation of the switching line x + cx = 0 was understood as the equation of motion in our second scenario.

The first issue occurs due to control interruptions, as the related motion equations do not meet the traditional theorems on solution availability and uniqueness. When traditional approaches aren't appropriate, regularisation or replacing the original problem with a closely related one that can be solved using known methods is the standard approach. Regularization is defined as the isolation of discontinuity sites (if any exist) by taking into consideration the delay or hysteresis of a proposed inverter, short time variables in an ideal model, and replacing a discontinuity function with a continuous estimate. The boundary layer is depicted in Figure 5.

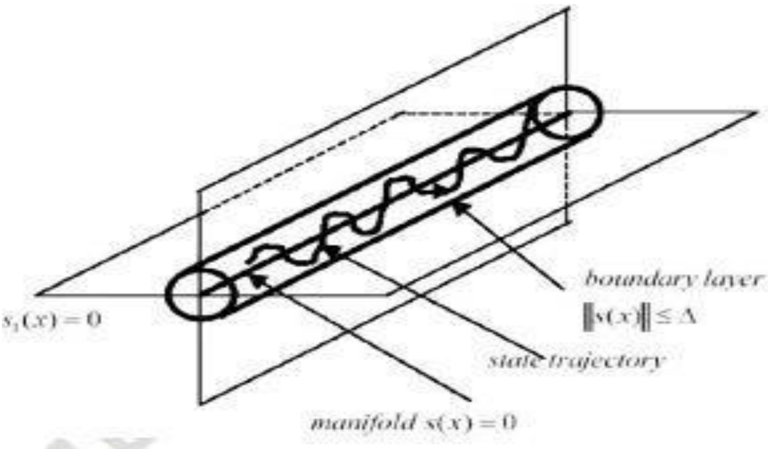


**Figure 5. Layer of the boundary**

### 7. Neuro-fuzzy systems:

Jyh-Shing Roger Jang presented neuro-fuzzy systems in his thesis ANFIS in 1992. They employ the artificial neural concept to express the architecture of a fuzzy system as a deep network. A neural net without a cycle is known as a MLP. [15] A vector net is supplied to the input nodes, and the network sends an output vector to the hidden layers. [16-18] The components of the input image are graded by the network parameters and blended in the concealed neurons in hidden layer between such 2 layers. [19] Figures 6 and 7 show a feed - forward neural network and the structure of a convolution neural network, respectively.

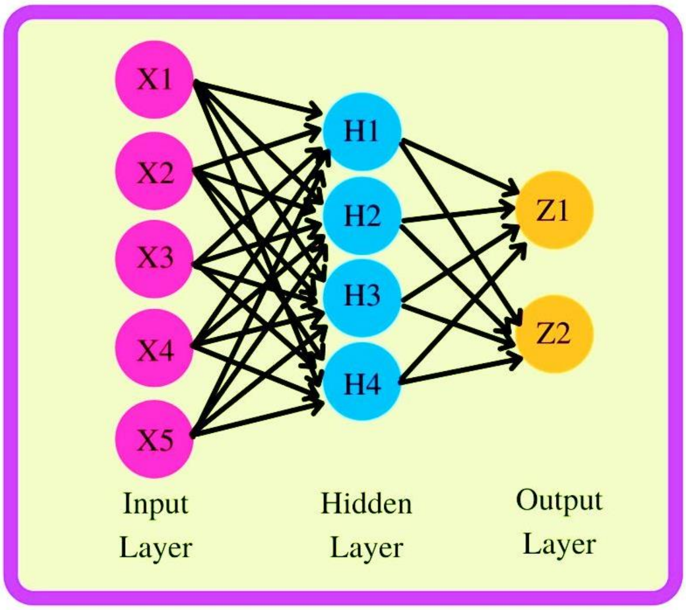


**Figure 6: A feedforward neural network is an example of this type of network.**

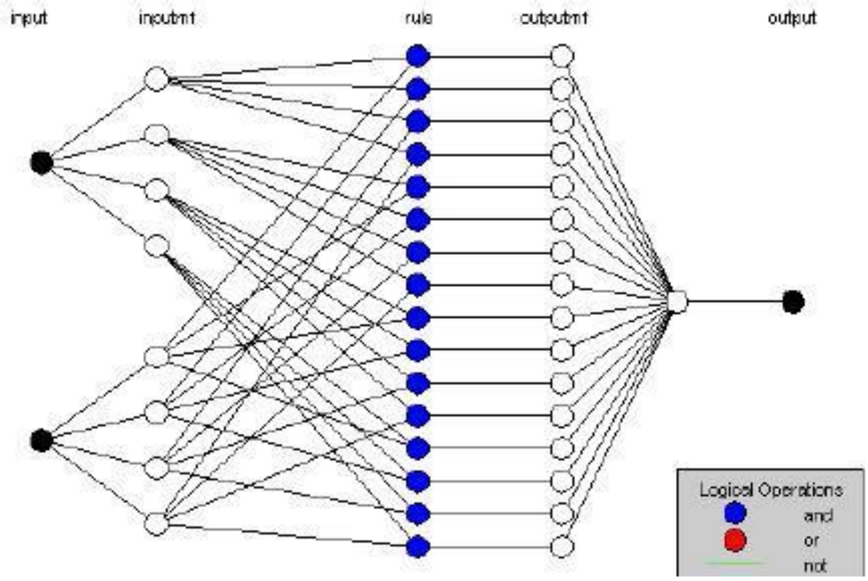


**Figure 7: A neuro-fuzzy system's structure**

**8. Final thoughts:**

This study describes a method for designing sliding - mode and manifolds to stabilise nonlinear unpredictable systems. It also addresses the use of a fuzzy controller to speed up the negative output conversion process. The goal of enlarging the inner limit of the region of pull for shuttered dynamics was also achieved. With the use of (bilinear) mean square programming, a method is suggested to construct a control that assures both ergodic and limited time stability. An incremental algorithm is used to search through a sliding mode manifold with Lyapunov functional simultaneity. It also ends the set of estimated zone of attraction for lower order backstepping dynamics in the situation of local stabilization.

**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. A. 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, Tana Luciya Joji, 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. Sakthivel R., Sundareswari K., Mathiyalagan K., Arunkumar A., Anthoni S.M." Robust reliable H∞ control for discrete-time systems with actuator delays" *Asian Journal of Control* (2015).

9. 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.

10. Balusamy R., Kumaravel P., Renganathan N.G "Dielectric and electrical properties of lead zirconate titanate" *Der Pharma Chemica* (2015).

11. Veeranna, G., K. Vaisakh, and R. Srinivas Rao. "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.

12. 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.

13. Ramash Kumar, K. "FLC and PWM SMC for KY boost converter." *Journal of Circuits, Systems and Computers* 28.11 (2019): 1950184.

14. 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.

15. 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.

16. Prabakaran K., Vengataasalam S., Balaji G. "Numerical analysis of state space systems using single term Haar wavelet series" *Applied Mathematical Sciences* (2014).

17. Mohd Zaihidee, Fardila, Saad Mekhilef, and Marizan Mubin. "Robust speed control of PMSM using sliding mode control (SMC)—A review." *Energies* 12.9 (2019): 1669.

18. Jayapandian N., Rahman A.M.J.M.Z., Poornima U., Padmavathy P." Efficient online solar energy monitoring and electricity sharing in home using cloud system" *IC-GET 2015 - Proceedings of 2015 Online International Conference on Green Engineering and Technologies* (2016).

19. 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.

20. 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.

21. Sankar, VV Arun, AP Arun Pravin, and P. Suresh. "Load and Emission Characteristics of Pongamia Pinnata Oil in ACI Engine." *International Journal of Engineering & Technology* 7.2.24 (2018): 518-526.

22. 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.

23. Krishnan, S. Navaneetha, P. Sundara Vadivel, 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.