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PEDELEC ASSISTANCE AUTOMATION AND CONTROL BY ANFIS USING MATLAB

TY B.Tech. Mini Project Report

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PEDELEC ASSISTANCE AUTOMATION AND CONTROL BY ANFIS USING MATLAB

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submitted in partial fulfilment of the requirements for the award of the degree

of

Bachelor of Technology

in

ELECTRONICS AND TELECOMMUNICATION ENGINEERING

BY

Sourabh Kalel, Vijay Talekar

SCHOOL OF ELECTRICAL ENGINEERING & TECHNOLOGY

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CERTIFICATE

It is hereby certified that the work which is being presented in the TY B.Tech. Mini Project Report entitled **"PEDELEC ASSISTANCE AUTOMATION AND CONTROL BY ANFIS USING MATLAB",** in partial fulfillment of the requirements for the award of the **Bachelor of Technology in Electronics Engineering** and submitted to the **School of Electrical Engineering of MIT Academy of Engineering, Alandi(D), Pune, Affiliated to Savitribai Phule Pune University (SPPU), Pune** is an authentic record of work carried out during an Academic Year 2019-2020, under the supervision of **Name of Advisor(s), School of Electrical Engineering.**

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Name………………………………

Affiliation…………………………

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1. Sourabh Kalel
2. Vijay Talekar

ABSTRACT

In recent years, we have observed a dramatic shift in mentality of UN and top nations towards the climate change due the crisis it has brought with it. Temperature rise on land is about twice the global average increase which is causing Arctic and Antarctic glacier to melting at alarming rate. As per the Paris Agreement signed in 2016, long-term temperature goal is to keep the rise in global average temperature to well below 2 °C (3.6 °F) above pre-industrial levels of which, 1.2 °C has already been reached by the end of 2020. With such great concern over rising global average temperature and climate change, it is fair to state that environment friendly mobility is need of the hour.

Apart the climate crisis, there's prevailing health crisis. Insufficient physical activity and sedentary behaviour are major risk factors for death from cardiovascular diseases, cancer, and diabetes worldwide. The positive effects of physical activity have prompted leading health organizations to create activity guidelines to benefit health. However, globally, 25% of adults do not meet recommendations for physical activity. Physical activity is important for all ages and should be integrated into daily life; for example, the workplace is a key setting where sedentary behaviour can be reduced

Light Electric Vehicle (LEV) is the so-called green and eco-friendly ride for the common short distance commuters. LEV is set of electric bicycle a.k.a. Pedelec, electric bike, electric scooter, etc. One of these which has gained enormous popularity recently is electric bicycle a.k.a. 'Pedelec' which is the focus of this study. Pedelec, in general, is driven by user's pedal force and the battery power assisted motor. Fully electrically power assisted bicycles are also a type of E-bicycle which is driven only on motor backed by battery power. However the study is restricted to Pedelec and it's assistance automation and control.

LIST OF FIGURES

CONTENTS

1. INTRODUCTION

A pedelec (from pedal electric cycle) or EPAC (*Electronically Power Assisted Cycles*), is a type of electric bicycle where the rider's pedalling is *assisted* by a small electric motor; thus it is a type of low-powered e-bike. However, unlike some other types of e-bikes, pedelecs are classified as conventional bicycles in many countries by road authorities rather than as a type of electric moped. Pedelecs include an electronic controller which cuts power to the motor when the rider is not pedalling or when a certain speed – usually 25 km/h (16 mph) or 32 km/h (20 mph) – is reached. Pedelecs are useful for people who ride in hilly areas or in strong headwinds. While a pedelec can be any type of bicycle, a pedelec city bike is very common. A conventional bicycle can be converted to a pedelec with the addition of the necessary parts, e.g., motor, battery, etc.

The e-bike is a bike with a battery-powered motor assisting the rider’s pedal-power. The riders choose the level of assistance, which kicks in as they pedal and then decreases and stops when a certain speed is reached (25 km/h for the pedal-assisted electric bicycle or *pedelec*, the most common e-bike, or 45 km/h for the *speed-pedelec*). Since the mid-2000s, sales have been rapidly increasing.

Figure 1.1: Modern Pedelec

In 2006, e-bikes represented only 1% of the new bikes sold (3,200 units), but by 2019 this had increased to 36% (133,000) (Velosuisse 2020), while by 2015, 7% of Swiss households owned at least one e-bike (OFS, and ARE 2017).

In the glimpse of such outreach and penetrating breakthrough in the market there is a lot of research going on automation of the assistance system in the pedelec. Many Artificial Intelligence and Soft Computing techniques are being studied and implemented. One such technique is Adaptive Neuro-Fuzzy Inference System (ANFIS) which is a hybrid of Neural Networks and Fuzzy Logic Control. In this study, we have researched and implemented ANFIS for automation of pedelec assistance which has yield better results than the traditional Fuzzy Inference technique.

1.1 Motivations

In recent years, we have observed a dramatic shift in mentality of UN and top nations towards the climate change due the crisis it has brought with it. Climate change is typically global warming driven by human-influenced emissions of greenhouse gases resulting in shift of normal temperature towards higher end. Temperature rise on land is about twice the global average increase which is causing Arctic and Antarctic glacier to melting at alarming rate. No. of cold days and nights has been decreasing since the dawn of the century. As per the Paris Agreement signed in 2016, long-term temperature goal is to keep the rise in global average temperature to well below 2 °C (3.6 °F) above pre-industrial levels, of which, 1.2 °C has already been reached by the end of 2020. With such great concern over rising global average temperature and climate change, it is fair to state that environment friendly mobility is need of the hour.

One of the major producers of greenhouse gases which is ultimately affecting environment is the usage of fossil based fuels like Petroleum and its counterparts. With the wide range of application, it has certainly cause havoc on the planet. International Energy Agency (IEA) claims that around 57% of the total Petroleum used worldwide is being used for transportation and mobility purposes. The internal combustion engines found to be in most of the Modern Motor Vehicles contribute majorly to this figure. Fossil fuel is not sustainable resource and its reported depletion is evident of this fact.

Figure below depicts what contributions human and nature is making for rise in global temperature.

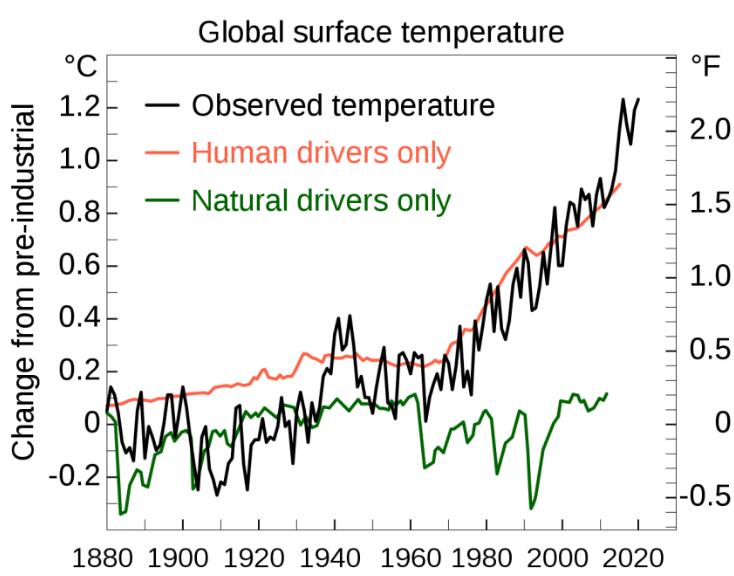


Figure 1.2: Global Surface Temperature

The usage of internal combustion engine vehicles indeed brings many societies a wealth of convenience and a great of evolution for transportation system. However, such closely linked and inseparable relationship with human also expedites the depletion of petroleum, where energy crisis is conceivable in the coming years. The need for sustainable energy production is fortunately being accomplished by electrical energy reducing fossil dependence. More and more applications are being electrified with keeping sustainability and climate change as in mind and one such is transportation and mobility.

1.2 Problem Statement

Optimize the battery power management and control by automating the pedelec commute using advanced intelligent algorithms and techniques.

Problems:

- *Power management in traditional pedelec is poor due to three modes.*
- *When user needs power value not exactly the same as the modes value then the battery may not be efficiently used.*
- *Reported cases of imperfect speed control during sharp turns*

1.3 Objectives and Scope

1. To automate the Speed Control using Soft Computing technique i.e. Adaptive Neuro-Fuzzy Inference System (ANFIS).
2. To build Neural Network(ANFIS) using DL libraries such as TensorFlow and Keras and tune using Genetic Algorithm(GA).
3. To create large dataset for training and testing of the model
4. To compare the results with traditionally used Speed Control techniques and conclude.

2. LITERATURE SURVEY

I. **Research Paper/Journal**

Title – Modeling, Design & Simulation of an Adaptive Neuro-Fuzzy Inference System (ANFIS) for Speed Control of Induction Motor

Author – Kusagur A., Kodad, S. F., and Ram, B. V. S.

Conference/ Journal – International Journal of Computer Applications 2010

Insights –

- Attempt is made to reduce the settling time of the responses
- Make the speed of response very fast by using ANFIS control strategy.
- The proper rule base is selected using an intelligently developed BPA.
- Formulated this complex control strategywhich has yielded excellent results.

II. **Research Paper/Journal**

Title – A Comparative Study of PID, ANFIS and Hybrid PID-ANFIS Controllers for Speed Control of Brushless DC Motor Drive

Author – Hidayat, S. Pramonohadi, Sarjiya and Suharyanto

Conference/ Journal – 2013 International Conference on Computer, Control, Informatics and Its Applications (IC3INA)

Insights –

- Presents a comparative study of various controllers for the speed control of Brushless Direct Current Motor (BLDCM)
- Compares performance of controllers like PID, ANFIS and Hybrid PID-ANFIS.
- Compares performance of controllers like PID, ANFIS and Hybrid PID-ANFIS.

III. **Research Paper/Journal**

Title – ANFIS: Adaptive Network-Based Fuzzy Inference System

Author – Jyh-Shing, Roger, Jang

Conference/ Journal – IEEE TRANSACTIONS ON SYSTEMS, MAN, AND CYBERNETICS

Insights –

- The architecture and learning procedure underlying ANF'IS (adaptive-network-based fuzzy inference system) is pre sented, which is a fuzzy inference system implemented in the framework of adaptive networks.
- Detailed implementation and concept proposal of ANFIS was first proposed in this paper.
- Comparisons with artificial neural networks and earlier work on fuzzy modeling are listed and discussed.
- Other extensions of the proposed ANFIS and promising applications to automatic control and signal processing are also suggested.

IV. **Research Paper/Journal**

Title – Multi-Sensor Information Fusion for Optimizing Electric Bicycle Routes Using a Swarm Intelligence Algorithm

Author – De La Iglesia, Daniel H.; Villarrubia, Gabriel; De Paz, Juan F.; Bajo, Javier

Conference/ Journal – 2011 International Conference on Computer, Control, Informatics and Its Applications (IC3INA)

Insights –

- Proposes an engine management system for e-bikes uses sensors to optimize battery energy and time.
- ANN used to estimate speed and consumption for each of the segments of a route.
- Evolutionary algorithm used for Optimization.

V. **Reference Book**

Title – Computational Intelligence Systems and Applications. Neuro-Fuzzy and Fuzzy Neural Synergis**.**

Author – Marian B. Gorzalczany

Publisher – Springer-Verlag Berlin Heidelberg

Insight –

- Presents new concepts and implementations of CI systems and a broad comparative analysis with several of the best-known neuro-fuzzy systems as well as with systems representing other knowledge-discovery techniques such as rough sets, decision trees, regression trees, probabilistic rule induction, etc.
- This presentation is preceded by a discussion of the main directions of synthesizing fuzzy sets, artificial neural networks and genetic algorithm.

VI. **Reference Book**

Title – Computational Intelligence and Its Applications. Evolutionary Computation, Fuzzy Logic, Neural Network and Support Vector Machine Techniques

Author – S. H. Ling and H. T. Nguyen

Publisher – Imperial College Press

Insight –

- This volume brings together many different aspects of the current research on intelligence technologies such as neural networks, support vector machines, fuzzy logics, evolutionary computing and swarm intelligence.
- Provides the state-of-the-art research on significant topics in the field of computational intelligence.
- Presents fundamental concepts and essential analysis of various computational techniques to offer a systematic and effective tool for better treatment of different applications.

VII. **Research Paper/Journal**

Title – A fuzzy Q-learning based assisted power management method for comfortable riding of pedelec

Author – C. Liu and R. C. Hsu

Conference/ Journal – 2015 6th International Conference on Automation, Robotics and Applications (ICARA)

Insights –

- Utilizes the fuzzy inference system to continuously infer the assisted power and the competing results are processed by Q-learning.
- The proposed assisted power management (APM) method provides an appropriate assisted power (action) adaptively according to the environmental changes

VIII. **Journal Article**

Title – The rise of the e-bike: Towards an extension of the practice of cycling?

Author – Patrick Rérat

Journal – Tailor and Francis Online Journal : Mobilities.

Insights –

- Based on a large-scale survey of 14,000 bike commuters in Switzerland.
- E-cycling and conventional cycling are compared in order to identify how and to what extent the e-bike expands the practice of cycling.
- Results indicate that the e-bike presents an opportunity to overcome some of the barriers faced by conventional cyclists, such as distance, gradient and physical effort.

3. SYSTEM DESIGN

3.1 Block Diagram/ Proposed System Setup

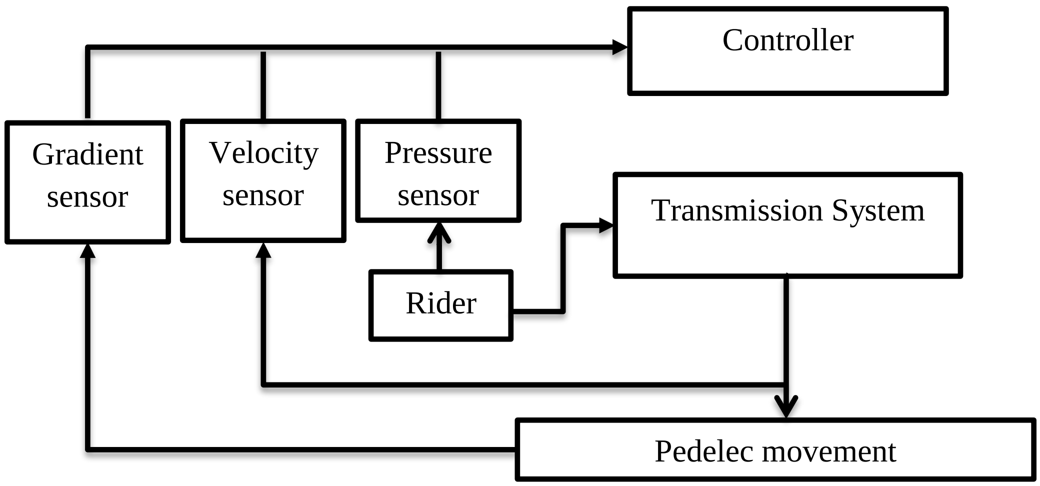


Figure 3.1: System Block Diagram

The system model of the proposed method is shown in -------, where the observable environmental variables for ANFIS Controller are road gradient and velocity which are sensed by the gradient sensor and velocity sensor, respectively, while the pedelec is moving, and the pedal force which is sensed by the torque sensor while the rider is treading the pedal. The power command of motor is given by the output of Controller to drive the motor which is powered by the chargeable battery. The motor assisted force and the pedal force is synchronized by the transmission system, and then the pedelec is propelled to move on.

3.2 Mathematical Modelling

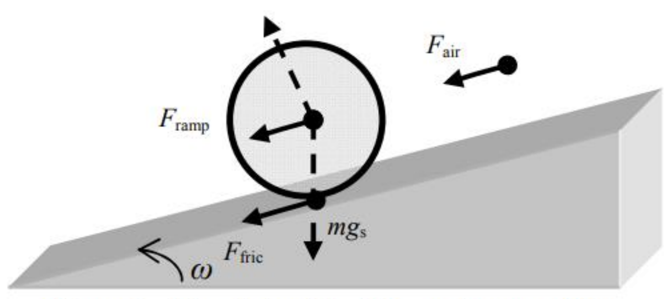


Figure 3.2: Environmental Forces

In order to move a bicycle forward with a certain speed, the rider needs to overcome the forces exercising on the vehicle. For example, for a bicycle rider to move the vehicle uphill at certain velocity there are three resisting forces, air drag, friction, and ramp drag forces, to be overcome.

The forces of F_{air}, F_{fric} and F_{ramp}, respectively, can be obtained by the following equations,

$$F_{air} = \frac{1}{2} C_d D_a A_f v^2$$
$$F_{fric} \equiv mgC_r \cos(\omega)$$
$$F_{ramp} \equiv mg \sin(\omega)$$

where C_d, D_a, and A_f respectively, are the drag coefficient of atmosphere, the atmospheric density, and the frontal area. C_r is the rolling coefficient of the bicycle's tire, g is the standard gravity of the Earth, and m is the gross weight of the rider and the vehicle. ω is the slope of the ramp. Hence, the total required input power (P_{req}) in moving the bicycle uphill at expected speed v_{exp} can be expressed as the following,

$$P_{req} = (F_{ramp} + F_{fric} + F_{air})v_{exp}$$

the friction and the air drag can be considered as constant assuming the same rolling coefficient and the frontal area such that the main dominated resistant force is the force induced by the ramp slope, F_{ramp}

$$P_{req} \approx F_{ramp} v_{exp}$$

the power provided from the pedalling of the rider and the assisted motor, P_{req}= $P_{pedal} + P_{motor}$, must be greater than the total power of the required expected power, Pexp, and the power in overcoming the environment change, ΔP_{env}, as below,

$$P_{pedal} + P_{motor} \geq P_{exp} + \Delta P_{env}$$

Which gives,

$$v = \frac{P_{pedal} + P_{motor}}{F_{ramp} + \Delta F}$$

The rider's peddling power, when combined with an appropriate assisted motor power, will move the pedelec forward with a constant velocity

ANFIS Design–

- Introduced by Jang in 1993. Is a marriage of "learning capability of Neural Networks" and "knowledge representation ability of Fuzzy Inference System".
- Neural Network's lack of transparency and Fuzzy logic's weakness of learning can be conquered.
- Based on Takagi and Sugeno Fuzzy Approach -

Rule base - If x_i is A_i AND x_i is B_i Then $f_i = c_{i1}x_1 + c_{i2}x_2 + c_{i0}$

- ANFIS is able to get crisp input, represent linguistically by generating membership function and fuzzy rules, and again generate corresponding crisp outputs.
- Widely used applications that deal with crisp inputs and outputs.

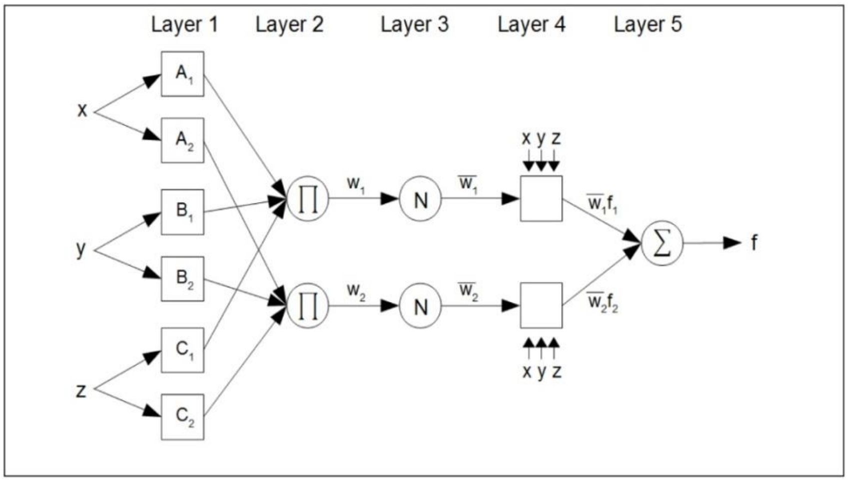


Figure 3.3: ANFIS network

Layer 1
Every node i in this layer is an adaptive node which a node activation function parameter. The output of every node is the membership function degrees which given by input membership function as the following

$$\mu(x) = \frac{1}{1 + \left|\frac{x - c}{a}\right|^{2b}}$$

Where {a,b,c} are the parameter set. As the value of these parameters changes, the bell-shaped function varies accordingly, thus exhibiting various forms of membership functions for fuzzy set.

Layer 2
Every node in this layer is fixed node is labelled Π , whose output is the product of all the incoming signals as below

$$w_r = \prod_{i=1}^{n} \mu_{A_{ir}}(x_i')$$

Each node output represents the firing strength (α predicate) of a rule. In general, any other T-norm that performs fuzzy AND can be used as the node function in this layer.

Layer 3
Every node in this layer is a fixed node labelled N. The i^{th} node calculates the ratio of the gain ratio i^{th} rule firing strength (α predicate) to the sum of all rules firing strengths as below

$$\overline{w}_r = \frac{w_r}{\sum_{j=1}^{R} w_j}$$

For convenience, outputs of this layer are normalized firing strengths

Layer 4
Every node i in this layer is an adaptive node with a node function is

$$\overline{w_i} f_i = \overline{w_i}(c_{i1}x_1 + c_{i2}x_2 + c_{i0})$$

Where $\overline{w_i}$ is a normalized firing strength from layer 3 and { c_{i1}, c_{i2}, c_{i0} } are the parameter set of this node. Parameters in this layer are referred to as consequent parameters.

Layer 5
The single node in this layer is a fixed node labelled $\sum$, which computes the overall output as the summation of all incoming signals as following,

$$\sum_i \overline{w_i}\, y_i = \frac{\sum_i \overline{w}_i y_i}{\sum_i w_i}$$

The parameter to be trained are a, b and c of the premise and { c_{i1}, c_{i2}, c_{i0} } of the consequent parameters.

ANFIS is trained using hybrid learning algorithm that consists of two steps such as feed forward pass and backward pass. More specifically, in the forward pass of the hybrid learning algorithm, node outputs go to forward until layer 4 and consequent parameters are identified by the least squares method. In the backward pass, the error signal propagates backward and the premise parameters are updated by gradient descent.

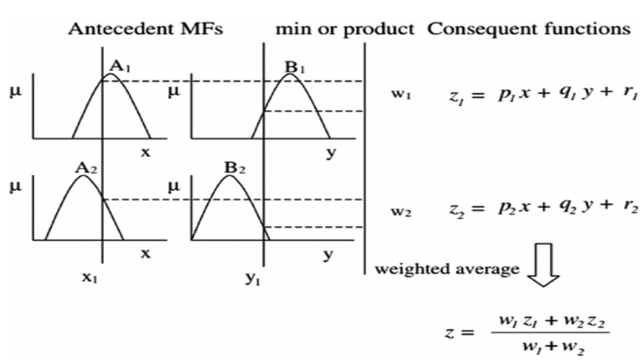


Figure 3.4: Fuzzy Inference Plot

3.3 Software Requirements

3.3.1 MATLAB Neuro-Fuzzy Designer Tool –

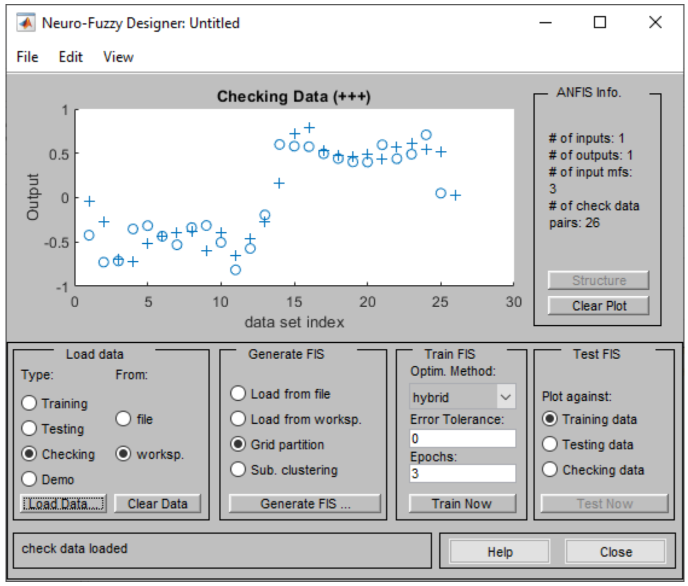


Figure 3.5: NFD Tool

The Neuro-Fuzzy Designer tool was used to design, train, and test adaptive neuro-fuzzy inference systems (ANFIS) using input/output training data. NFD Tool was quite useful for the study which was extensively used while performing tasks like –

- Tune membership function parameters of Sugeno-type fuzzy inference systems.
- Automatically generate an initial inference system structure based on your training data.
- Modify the inference system structure before tuning.
- Prevent over fitting to the training data using additional checking data.
- Test the generalization ability of your tuned system using testing data.
- Export your tuned fuzzy inference system to the MATLAB workspace.

3.3.2. Atom Editor and Compiler–

Atom is a hackable text editor for the 21st century, built on Electron, and based on everything we love about our favorite editors. We designed it to be deeply customizable, but still approachable using the default configuration.

In our concerned study, Atom was used to write python script for generating large dataset of around 2300 data samples. More on generation of this dataset is discussed in next chapter i.e. section 4.1

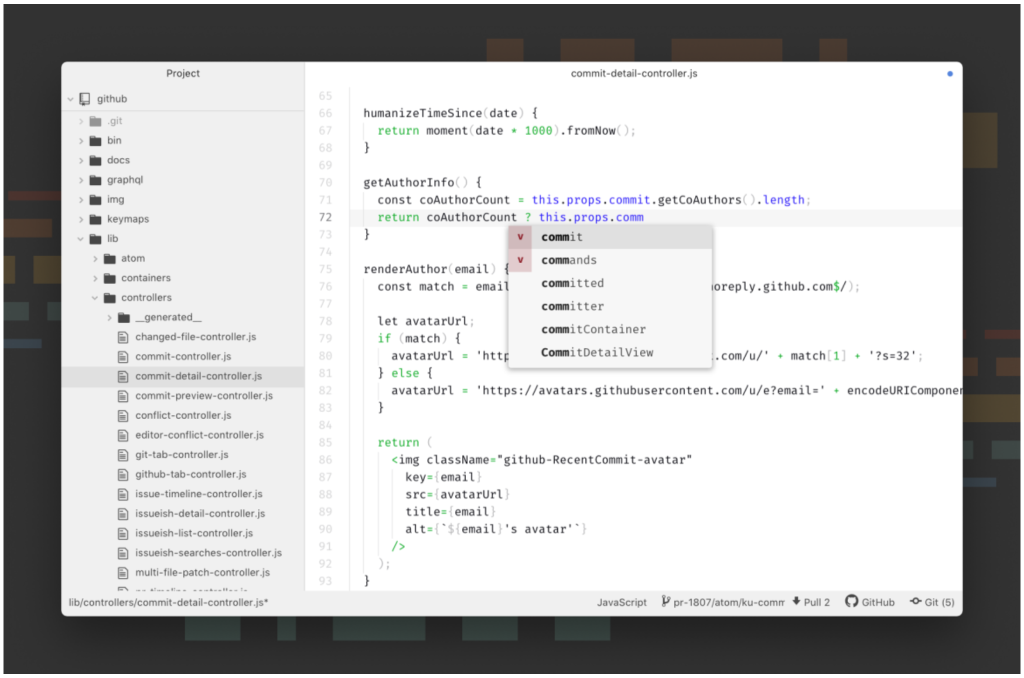


Figure 3.6: Atom Interface

Code snippet –

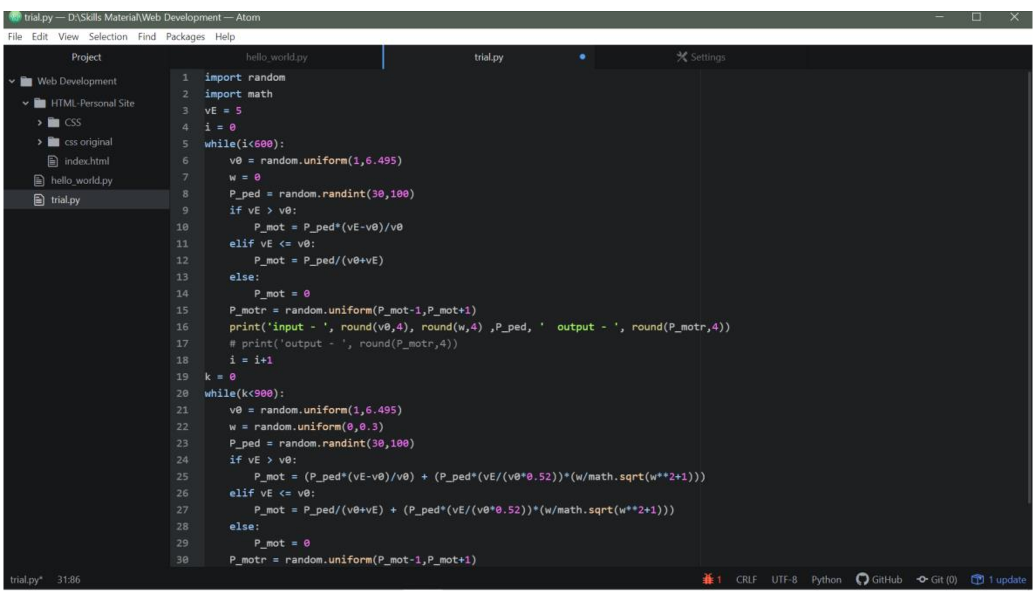


Figure 3.7: Python Code in Atom

4. IMPLEMENTATION DETAILS

In the system model of pedelec, ANFIS system relies on three sensor input variables (ω, v, P_{pedal}) which are the gradient of the road, the vehicle velocity, and the pedaling power in generating an inferred continuous action U. For an input state S(ω, v, P_{pedal}) which is considered as the rule premise with the truth value αi(s) be calculated from each rule i by given the corresponding membership functions.

4.1 Algorithm

ANFIS being an adaptive network needs to be trained and tested for its efficiency and error %.
For a typical Adaptive network model to be trained for any application needs to be provided with a large dataset. Training occurs with help of some widely popular and subtle techniques such as Feed forward pass and Back Propagation.
MATLAB's inbuilt Neuro-Fuzzy tool allows us to feed the dataset and train the model on the go. Unfortunately, the dataset for our concerned study with labelled variables (ω, v, P_{pedal}, P_{motor}) was not available. Hence the Dataset for the study was created indigenously using Python's Random and Math modules. The mathematical model to find relation between these variables was referred (as discussed in Section 3.2).
Large dataset of around 2300 samples was created for training and testing using this program code.

Parameters for the input variables were taken as mentioned in table –

Input Variable	**Range**	**Ideal Value**
Velocity(m/s) - v	0 – 6.954	5.00
Gradient ratio - ω	0 – 0.3	0.124
P_{pedal}(in Watts)	30 – 100	80

Python code that was used to generate large no. of data samples is as follows,

Code –

```
import random
import math

vE = 5
i = 0
while(i<600):
   v0 = random.uniform(1,6.495)
   w = 0
   P_ped = random.randint(30,100)

   if vE > v0:
```

```
        P_mot = P_ped*(vE-v0)/v0
    elif vE <= v0:
        P_mot = P_ped/(v0+vE)
    else:
        P_mot = 0


    P_motr = random.uniform(P_mot-1,P_mot+1)
    print('input - ', round(v0,4), round(w,4) ,P_ped, '  output - ', round(P_motr,4))
    # print('output - ', round(P_motr,4))

    i = i+1

k = 0
while(k<900):
    v0 = random.uniform(1,6.495)
    w = random.uniform(0,0.3)
    P_ped = random.randint(30,100)

    if vE > v0:
        P_mot = (P_ped*(vE-v0)/v0) + (P_ped*(vE/(v0*0.52))*(w/math.sqrt(w**2+1)))
    elif vE <= v0:
        P_mot = P_ped/(v0+vE) + (P_ped*(vE/(v0*0.52))*(w/math.sqrt(w**2+1)))
    else:
        P_mot = 0

    P_motr = random.uniform(P_mot-1,P_mot+1)
    print('input - ', round(v0,4), round(w,4) ,P_ped, '  output - ', round(P_motr,4))

    k = k+1
```

4.2 Results

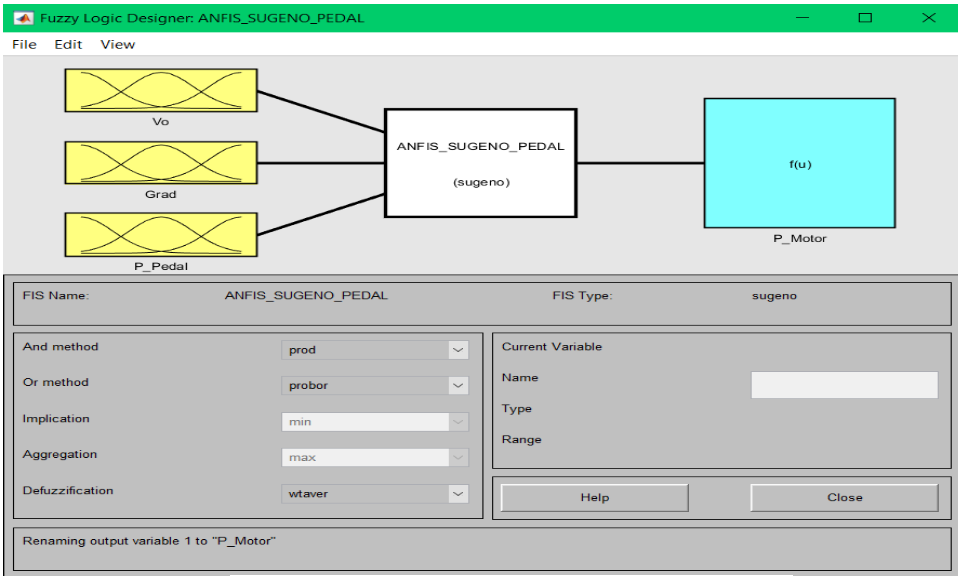
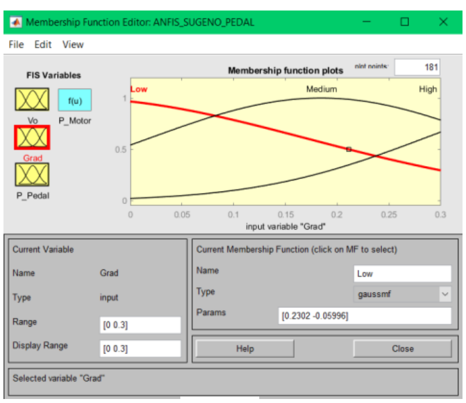
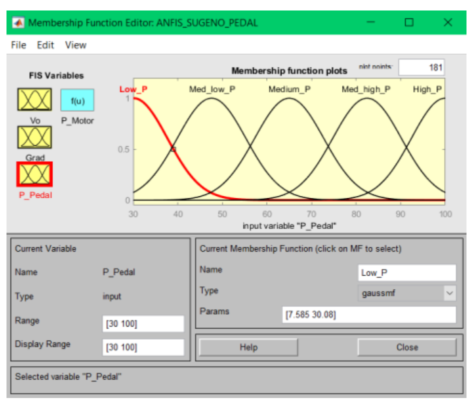


Figure 4.1: Sugeno Fuzzy Designer



(a)



(b)

(c)

Figure 4.2: Membership Functions (a) – Gradient, (b) – Pedal Pressure, (c) - Velocity

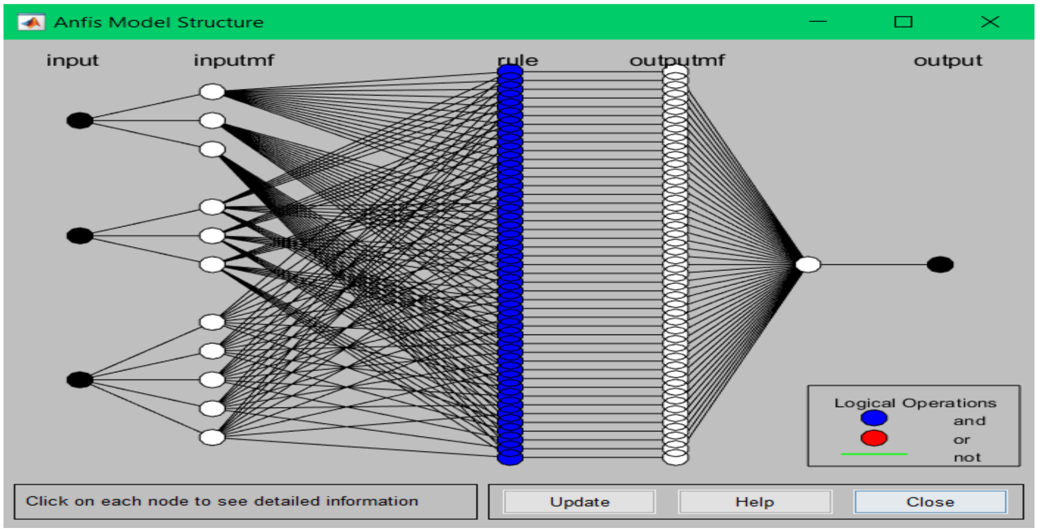


Figure 4.3: ANFIS Simulated Structure

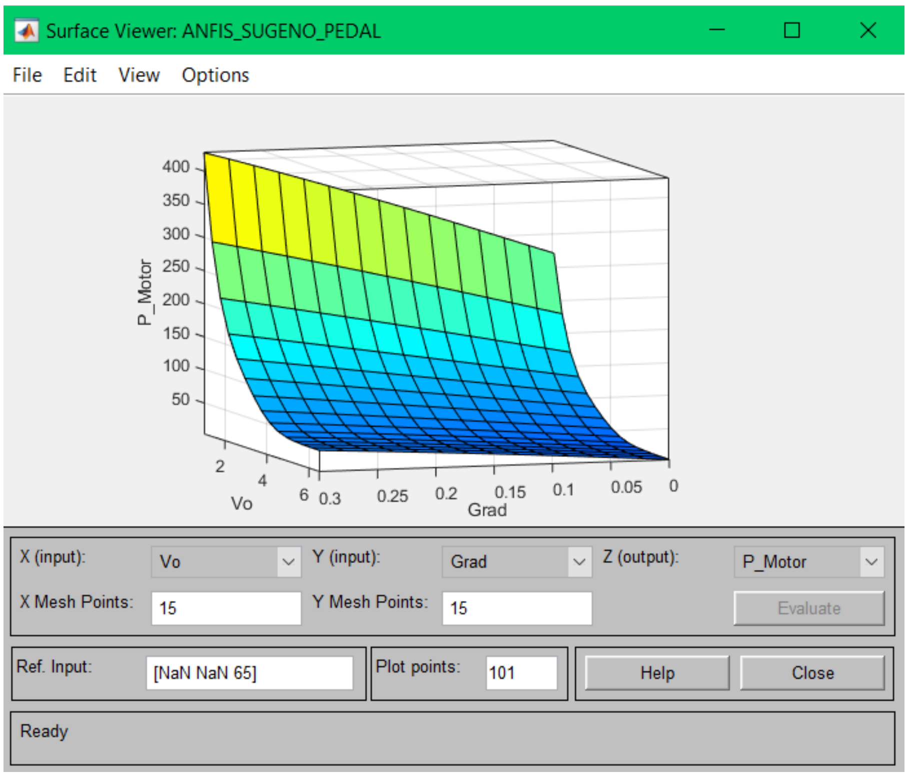


Figure 4.4: Surface View of model

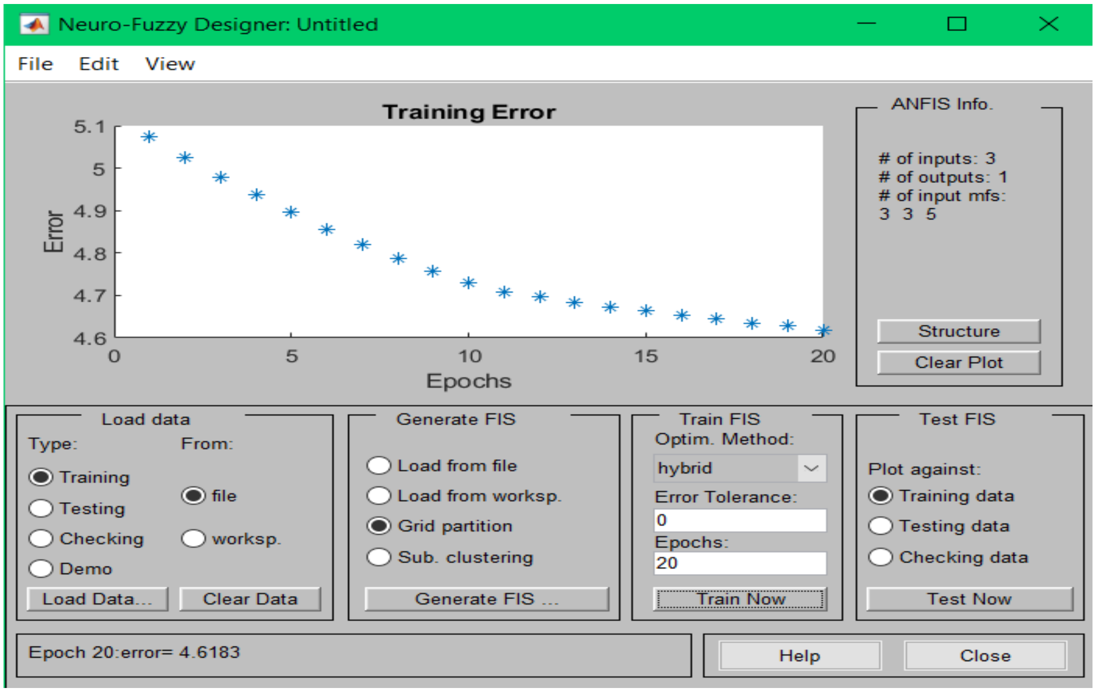


Figure 4.5: Epoch and Training Plot of model

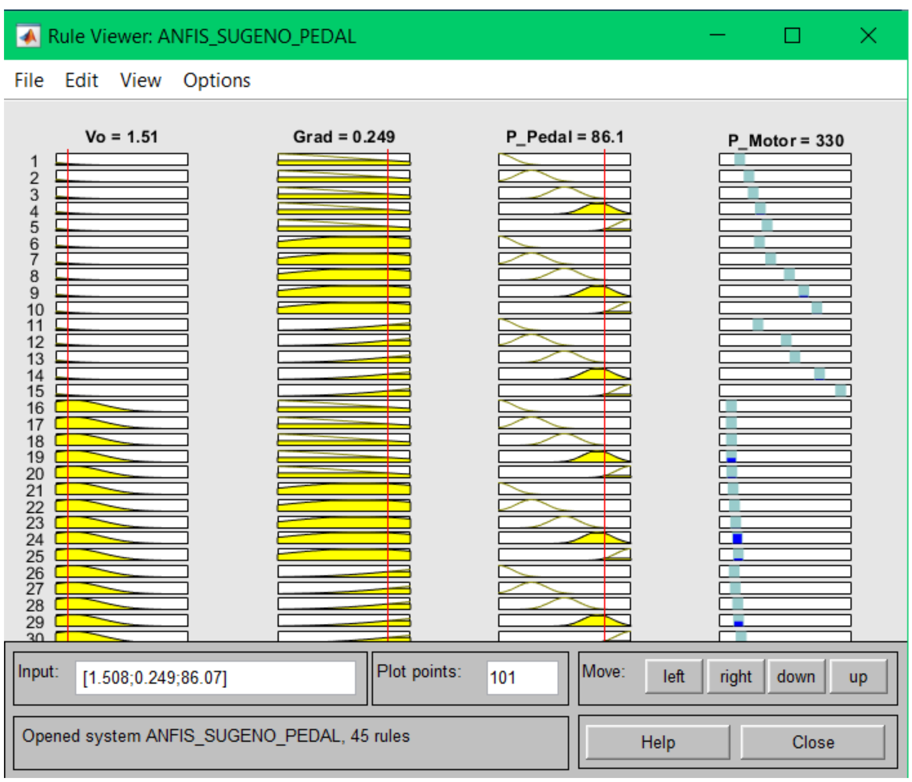


Figure 4.6: Result Rule View

4.3 Discussion

Traditional Artificial Intelligence have proved to be effective in handling problems characterized by exact and complete knowledge representation. However, there has been observed these systems may perform poorly while dealing with imprecise, uncertain and incomplete data and information which significantly contribute to the description of many real world problems, both physical systems and processes. There has been growing interest in algorithms which rely on analogies to natural processes and humanlike problem solving. Crisp uncertainties, lingual limits, and fuzzy data has been surfacing recently on many mechanical systems. This type of decision making can be a boon to the autonomous mobility where humanlike decision making is the need. One such application which is gaining popularity is the E-bicycle range of Light Mobility vehicles.

Adaptive Network Fuzzy Inference Systems (ANFIS) belongs to Computational Intelligence group of algorithms which is based on Sugeno Fuzzy model and its parameters are optimised with Neural Network approach. In this study, we have used this model to test and use it to automate the process of pedelec assistance so that the rider's is at more comfort and safe from manual errors.

For this study, many research papers and reference books were referred to get some insights before proceeding and to create a firm foundations to build up on. Many of them have a good amount of contribution towards this study. MATLAB's Neuro-Fuzzy Designer Tool was used for designing modelling the ANFIS model. For training purpose, Dataset was created using Random Module of Python. This has to be done because Pre-proposed dataset was not readily available. Around 2800 samples of labelled data were acquired and feed to the model for training and testing purpose. Around 70% of this data was used for training and other 30% was used for the testing of the model. Epoch value was set as 20. After results have been analysed. The model had accuracy of 95.39% with error of 4.61%. This is very positive figure as far as our application of Pedelec is concerned.

5. CONCLUSION & FUTURE SCOPE

The project aims at finding new and advanced solution the Pedelec Assistance System. The traditional way of switching between dedicated modes can be successfully replaced by automatic switching by ANFIS. This can also be a boon for the Battery Power Management in Pedelec as power will be only supplied as much as is required. This can help in ensuring the safety and Comfort of the ride. User can now enjoy the ride rather than worrying about the battery status and switching between the desired modes. The model aims at being precise in making the fuzzy and lingual humanlike decisions. As per the findings it has been successfully able to live up to the expectations.

This project can be further taken to be implemented on wide range of applications. More mechanical systems like Autonomous Vehicles (AV), Industrial Robotics, Large scale Energy management systems, Medical Applications, can benefit from this technique. The need for humanlike problem solving will only rise with technological advances. E-mobility is the mobility of the future. The demand is tend to rise as humanity has finally realized that it won’t be able to sustain at the expense of leveraging environment.

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