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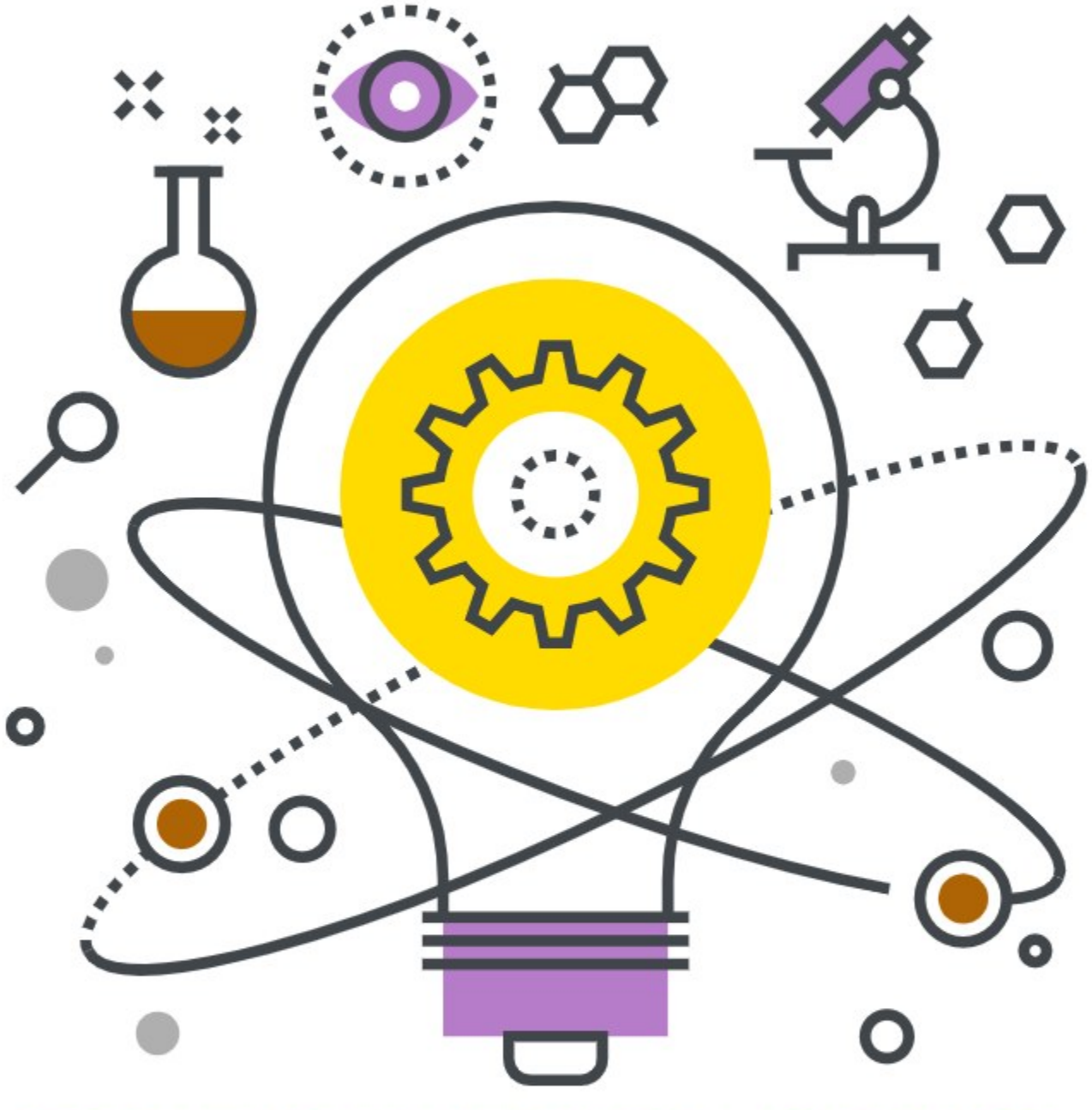

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A PUBLICATION OF
DEPARTMENT OF ELECTRICAL ENGINEERING
UNIVERSITY OF ENGINEERING AND TECHNOLOGY, LAHORE

MESSAGE FROM THE VICE CHANCELLOR

University of Engineering and Technology is an institution, which has always nurtured its students to set and achieve lofty goals by providing them the freedom to polish their skill set through curricular and co-curricular activities. A commendable product of such efforts and skills is Elektron, a magazine by the Department of Electrical Engineering, produced by the students of the EED, UET Lahore. Elektron reflects the creative minds of the students of Electrical Engineering and their abilities to breathe life into their innovative ideas.

To make this magazine a constant source of guidance and inspiration for the masses, the work done by the team Elektron is indeed, highly appreciated and acknowledged. The efforts put forth by the team Elektron should serve as a motivation for other students of UET Lahore to embark upon similar initiatives. I wish them best in their future endeavors.

Stay Blessed.

Prof Dr. Nasir Hayat

Vice Chancellor

University of Engineering and Technology,

Lahore

MESSAGE FROM THE CHAIRMAN

The aphorism "publish or perish" asserts the importance of publishing the scholarly work by the faculty and students. The Department of Electrical Engineering, historically, has been highly reputed for its outstanding undergraduate program. It has never been more important to involve undergraduate students in research. To publish the work carried out by under graduates has always been a challenge, due to the lack of availability of proper forum of this purpose, This is no more a limitation due to the introduction of the Elektron magazine. The Elektron team has put an extensive effort to make the idea a realization. The Elektron provides an excellent opportunity to both undergraduate as well as graduate students to publish their work. I believe this initiative will go a long way and will be pivotal in defining the careers of many.

Prof Dr. Muhammad Tahir

Chairman,

Department of Electrical Engineering,

University of Engineering and Technology,

Lahore

MESSAGE FROM THE EDITOR-IN-CHIEF

Elektron is a multidisciplinary publication dedicated to making complex research accessible and engaging for a broad audience, especially the matriculation, intermediate, and early year BS students of domains of sciences, pre-engineering and engineering. We aim to bridge the gap between academia and the public through clear explanations, graphical representations, and insightful analyses.

The key objectives of this magazine are,

- Explaining Research: The research articles are usually very intensive in usage of complex language, mathematical concepts. For the better understanding of the readers, the research be presented in an easily understandable form, avoiding too complex mathematical forms.
- Encouraging Visual Communication: Utilizing engaging graphical representations and illustrations are always catchy and help to make scientific and mathematical concepts more accessible and intuitive for our readers.
- Featuring Review and Analytical Articles: Publish comprehensive review articles that offer deep insights into certain research domains for the new researchers. These articles provide the interested readers with sufficient information on the works published in a particular research domain. Feature articles explore potential new research avenues, by the experts of a particular research domain.
- Fostering Innovation and Addressing Local Issues: Highlight interdisciplinary research and its potential to solve pressing local and societal issues.
- Industry Engagement: Encourage Large enterprises and SMEs to advertise their products, processes, and innovations.Moreover, inviting industry professionals to write about the R&D challenges they face, seeking solutions from our learned readership and bringing collaboration between academia and industry.
- Highlighting Peer Contributions: Recognizing and acknowledging significant contributions from researchers across various domains of knowledge.Featuring profiles, interviews, and articles that showcase the impactful work and breakthroughs achieved by peers, fostering a sense of community and collaboration among researchers.

We encourage the audience, who are science and knowledge enthusiasts, and want to show up as authors, to submit your articles at elektron.eed@uet.edu.pk

Dr. Muhammad Salman Fakhar

Editor-in-Chief, Assistant Professor

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وَقَالُوۡۤا ءَاِذَا كُنَّا عِظَامًا وَّرُفَاتًا ءَاِنَّا لَمَبۡعُوۡثُوۡنَ خَلۡقًا جَدِيۡدًا

﴿۴۹﴾ قُلۡ كُوۡنُوۡا حِجَارَةً اَوۡ حَدِيۡدًا ﴿۵۰﴾ اَوۡ خَلۡقًا مِّمَّا يَكۡبُرُ

فِىۡ صُدُوۡرِكُمۡ‌ ۚ فَسَيَقُوۡلُوۡنَ مَنۡ يُّعِيۡدُنَا‌ ؕ قُلِ الَّذِىۡ فَطَرَكُمۡ اَوَّلَ

مَرَّةٍ‌ ۚ فَسَيُنۡغِضُوۡنَ اِلَيۡكَ رُءُوۡسَهُمۡ وَيَقُوۡلُوۡنَ مَتٰى هُوَ‌ ؕ قُلۡ عَسٰٓى

اَنۡ يَّكُوۡنَ قَرِيۡبًا ﴿۵۱﴾

And they say ⌜mockingly⌝, “When we are reduced to bones and ashes, will we really be raised as a new creation?”. Say, ⌜O Prophet,⌝ “⌜Yes, even if⌝ you become stones, or iron, or whatever you think is harder to bring to life!” Then they will ask ⌜you⌝, “Who will bring us back ⌜to life⌝?” Say, “The One Who created you the first time.” They will then shake their heads at you and ask, “When will that be?” Say, “Perhaps it is soon!”

Al-Quran [17: 49-51]

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UNLOCKING THE POWER OF AI ASSISTANCE WITH NEXCUBATOR

We are living in a society where technology and digital transformation are overriding. AI services are changing the ground rules making production more efficient than ever. However, even though the technology has its own merits, it also presents problems that need to be solved. A role player here is Nexcubator, offering complete AI solutions that turn these challenges into opportunities.
Let's discuss the collaboration between AI assistance and Nexcubator.

Efficient & Productive

It is Nexcubator's use of AI to switch the control of the repetitive tasks so that the employees concentrate on a more strategic part of the program, which is of utmost importance to the staff. High levels of the companies' productivity can be attained through this. Such organizations will be able to reach the latest summits of productivity and surge up the economy.

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Using the assistance of AI, Nexcubator allows enterprises to give personalized customer experiences in large quantities. Via the acquisition of customer data through making customer engagements, Nexcubator empowers businesses to guarantee that they offer individual communication to them and individual products that will address their preferences and requirements, as a result, they will feel more special and stay loyal and satisfied, in the end.

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The Nexcubator platform allows companies to be proactive by using real-time data. As a result of the employment of AI solutions to explore and analyze ever-growing datasets, organizations can perceive trends, predict the future and come up with more effective strategies.

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Nexcubator enhances business processes by automating repetitive tasks, reducing errors, and minimizing downtime. Whether it's inventory control or supply chain optimization, Nexcubator ensures smooth and efficient operations across the business.

Innovation & Competitive Advantage

AI drives innovation by enabling companies to explore new activities and uncover hidden opportunities. Nexcubator's AI tools help firms enhance their market positions and stay ahead of trends, allowing them to lead in their respective sectors.
Setting up AI assistance is not that easy, considering integration complexity, security of data, algorithmic bias, user training, and scalability. Nexcubator takes care of all these concerns through end-to-end support and cutting-edge solutions.

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Implementing AI assistance may be demanding for companies lacking specialized skills and resources. Nexcubator simplifies this process with its user-friendly and extensive support services, facilitating easier AI integration.

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Data security and privacy come first at Nexcubator; this is done through strong encryption protocols and compliance standards to protect sensitive data. Notably, Nexcubator ensures that the clients enjoy protection of data from unauthorized access, most importantly from any breach, thus protecting it secure at all times.

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NETWORK RECONFIGURATION IN SMART DISTRIBUTION GRIDS

By Muhammad Ahmad Iqbal (m.ahmadiqbal@hotmail.com)

Abstract

Network reconfiguration (NR) is a well-accepted technique for enhancing power grid operational flexibility. It serves various purposes, such as power loss reduction, voltage profile improvement, and renewable grid integration. This paper sheds light on the real-world significance and mathematical formulation of NR problems, reviews various methods used in the literature to solve them, and showcases NR's potential applications in smart distribution grids.

Introduction

Reliance on fossil fuels for the sake of energy (electricity) has triggered catastrophic climate changes such as floods, heat waves, smog, and global warming. Sustainable and green energy grid integration is a pressing necessity to end reliance on these greenhouse gas emissions-based energy sources [1]. Advancements in technology have made the adoption of the network reconfiguration (NR) technique possible in power grids, contributing to these essential and timely efforts. NR gains its essence from the fact that smart distribution grids (SDGs) are operated in a radial (tree) structure through normally closed sectionalizing switches while having normally open tie lines [2]. The radial structure helps to limit short circuit current while tie lines increase the grid reliability.

Changing the open and close status of sectionalizing switches and tie lines of the SDGs is termed NR. The NR results in a new grid topology (structure) that can have different power flows and other state parameters affecting the desired objective of the grid operator [3]. Finding the optimal NR subjected to the desired objective function is a combinatorial problem. It is termed a non-convex non-deterministic polynomial-time hard (NP-hard) mixed integer non-linear (MINLP) programming optimization problem because of the load flow equations and binary nature of the switches involved [4].

Numerous NR problems and methods have been identified in the literature, addressing technical challenges in integrating sustainable energy into power grids while exploiting the potential of NR [5]. This paper will first highlight the significance of the NR in reducing one of the power grid's primary objectives (power loss reduction). Following this, problem formulation will be presented. Then, the methods used to solve NR and potential applications of NR will be demonstrated. Finally, the paper concludes with a summary of findings and implications for future research.

Network reconfiguration significance

The significance of network reconfiguration (NR) is demonstrated using an IEEE 33 bus feeder. The feeder consists of 37 branches and 33 buses, with an active load demand of 3.715 MW and a reactive load demand of 2.30 MVAR [6]. Initially, the configuration shown in Figure 1 has a power loss of 202.67 kW. After optimal NR, aimed at power loss reduction, the new configuration in Figure 2 shows a power loss of 139.55 kW [3]. This reduction of 31.14% highlights the effectiveness of NR in

minimizing power losses in smart distribution grids.

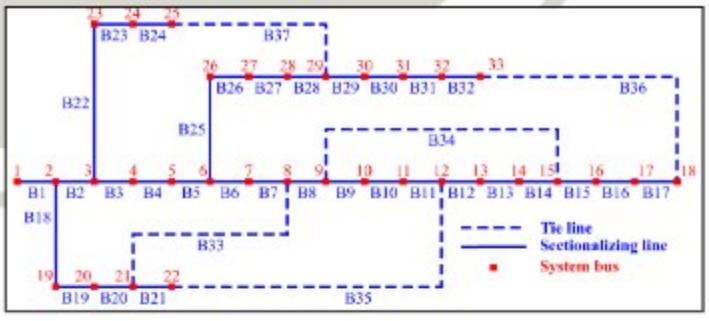

Figure 1. IEEE bus feeder before NR

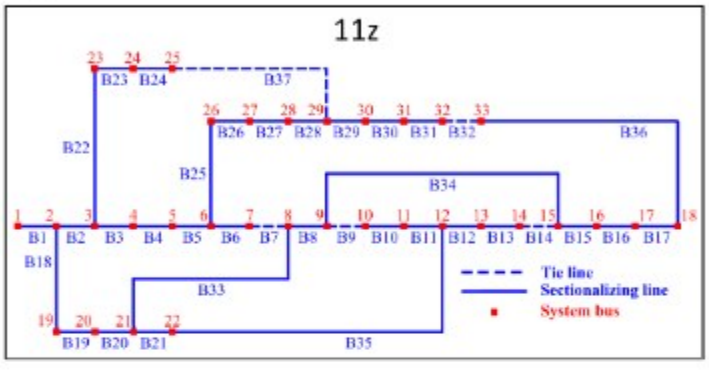

Figure 2. IEEE bus feeder after NR

Network reconfiguration significance

The NR problem can be formulated as a MINLP optimization problem [4]. Define B be a set containing all the branches of the network, N be the set containing all the buses of the smart distribution grid, N_{Slack} be the set containing the slack bus, and T be the set containing the time intervals. Let I_{ij}^t and v_{ij}^t be the squared current and voltage values at a time interval t , respectively. p_{ij}^t and q_{ij}^t are the active and reactive power flow from the bus i to j bus , respectively. p_i^t and q_i^t are the active and reactive power injections at the bus i , respectively. r_{ij} and x_{ij} are the resistance and reactance values between the buses i and j, respectively. $p_{load,i}^t$ and $q_{load,i}^t$ are the active and reactive power demands at the bus i, respectively. Interested readers are encouraged to refer to [4] for the comprehensive variables and equations (1) – (12) details.

$$Minimize \sum_{t\in T}\sum_{i\in N} p_i^t \qquad (1)$$

$$p_{ij}^t + p_{ji}^t = r_{ij} I_{ij}^t \qquad \forall t \in T(i,j) \in B \qquad (2)$$

$$q_{ij}^t + q_{ji}^t = x_{ij} I_{ij}^t \qquad \forall t \in T(i,j) \in B \qquad (3)$$

$$p_i^t = \sum_{j\in N_i} p_{ij}^t \qquad \forall t \in T\ i \in N \qquad (4)$$

$$q_i^t = \sum_{j\in N_i} q_{ij}^t \qquad \forall t \in T\ i \in N \qquad (5)$$

$$p_i^t = -p_{load,i}^t \qquad \forall t \in T\ \ i \in N/N_{slack} \qquad (6)$$

$$q_i^t = -q_{load,i}^t \qquad \forall t \in T\ \ i \in N/N_{slack} \qquad (7)$$

$$v_i^t = v_i^t - 2\left(r_{ij}p_{ij}^t + x_{ij}q_{ij}^t\right) + \left(r_{ij}^2 + x_{ij}^2\right)I_{ij}^t \qquad \forall t \in T(i,j) \in B \qquad (8)$$

$$\left(p_{ij}^t\right)^2 + \left(q_{ij}^t\right)^2 = I_{ij}^t v_i^t \qquad \forall t \in T(i,j) \in B \qquad (9)$$

$$v_{min,i}^2 \leqslant v_i^t \leqslant v_{max,i}^2 \qquad \forall t \in T\ \ i \in N/N_{slack} \qquad (10)$$

$$v_{slack}^t = 1 \qquad \forall\, t \in T \qquad (11)$$

$$0 \leqslant I_{ij}^t \leqslant I_{max}^2 \qquad \forall t \in T(i,j) \in B \qquad (12)$$

Radiality maintenance constraints

The distribution network must be operated in a radial structure to limit short-circuit currents otherwise the cost of protective equipment will rise significantly. The radial constraints are defined by (13) – (16). Define M1 be a large positive number to relax the equality constraint (8). Interested readers are encouraged to refer to [3] and [4] for a detailed description of the equations (13) – (16) mentioned below.

$$\sum_{(i,j)\in B} s_{ij} = |B| - (|N| - 1)\ \forall s_{ij} \in 1,0 \qquad (13)$$

$$v_i^t \leqslant M_1 s_{ij} + v_i^t - 2\left(r_{ij}p_{ij}^t + x_{ij}q_{ij}^t\right) + \left(r_{ij}^2 + x_{ij}^2\right)I_{ij}^t \qquad \forall t \in T(i,j) \in B \qquad (14)$$

$$v_i^t \leqslant -M_1 s_{ij} + v_i^t - 2\left(r_{ij}p_{ij}^t + x_{ij}q_{ij}^t\right) + \left(r_{ij}^2 + x_{ij}^2\right)I_{ij}^t \qquad \forall t \in T(i,j) \in B \qquad (15)$$

$$0 \leqslant I_{ij}^t \leqslant (1 - s_{ij})I_{max}^2 \qquad \forall t \in T(i,j) \in B \qquad (16)$$

Methods applied to solve NR

Many methods and optimization techniques are reported in the literature to solve the NR problems. They can be categorized into three major groups:

- Mathematical optimization [4]
- Metaheuristics optimization [3]
- Machine learning [7]

In [4], a mixed integer second-order cone programming (MISOCP) formulation is used to find the optimal NR using GAMS software. An

improved accelerated particle swarm optimization algorithm is used in [3] to solve the co-optimization problem of NR with battery storage. An explainable reinforcement learning-based method has recently been proposed by [3] to solve the distribution NR problem. A detailed review of the methods applied to the NR problems is presented in [5], and interested readers are encouraged to [5] for more in-depth insights into the methods applied. It is worth mentioning that artificial intelligence (metaheuristics and machine learning) based methods can handle multiperiod NR problems with ease compared to mathematical optimization. However, they lack the guarantee of global optimal solutions.

NR applications in SDGs

NR has the potential to create a pseudo-controllable load demand within the power grid, allowing for a discrete increase or decrease in the load demand per the operator's needs. This flexibility enables changes in SDGs' power flows, helping achieve various SDG objectives effectively. These objectives include:

- Power loss reduction [3]
- Voltage stability index improvement [8]
- Minimum voltage improvement [3]
- Renewable grid integration [4]
- Load balance index improvement [8]
- Reliability increase [9]
- Load restoration [10]
- Fault isolation [9]
- Service restoration [9]
- Electricity cost minimization [10]
- Congestion management [10]
- Total harmonic reduction of grid [11]

It can be seen that NR can affect a high number of vital objectives thus showing its potential to be used as a system service in renewable grids.

Conclusion

It is concluded that NR can significantly reduce the power losses of the distribution grids, and this problem can be solved by many state-of-the-art techniques, which include metaheuristics, machine learning, and mathematical optimization. NR offers a pseudo-controllable load for the power grid, which is discretely flexible and can thus be used to meet many SDG objectives simultaneously. Future research should explore NR's potential as a system service in a fully renewable grid to achieve sustainable and reliable power.

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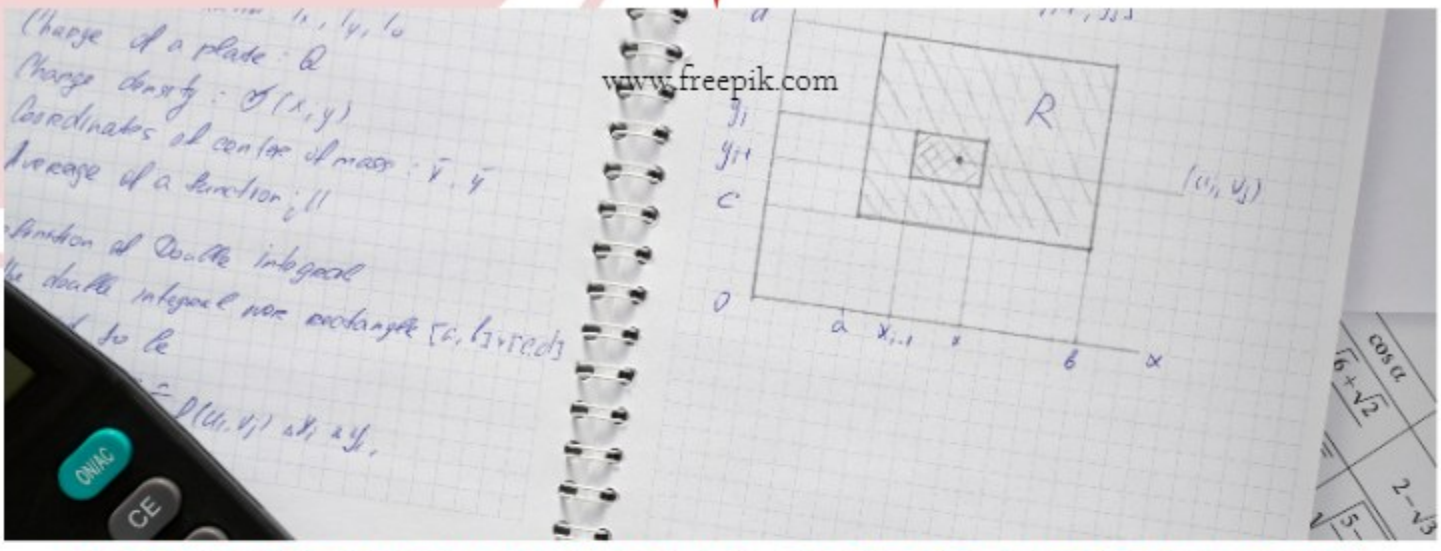

DEBUNKING PARTIAL DERIVATIVES FOR VECTOR CALCULUS

By Muhammad Anas Baig (anasbaig@outlook.com)

Abstract

The differentiation rules for scalar valued functions with scalar argument are well established even in the high school books. But a problem arises when extending the ideas to vector valued functions accepting scalars, vectors and even matrices as inputs. The conflict arises due to imperative assumptions held by experts of different fields in practicing vector calculus. For a calculation to be true involving matrices, output should come out to be true either row wise or column wise. But none of the calculations should involve both conventions. This idea of row wise vs column wise interpretation confuses people who are novices in Machine learning, Data Science, Economics, Estimation studies and many more to name. This article addresses this very fundamental issue and bridges a link between two approaches commonly used towards calculation of partial derivatives in applications involving mix of scalars, vectors and matrices.

Introduction

The application of vector differentiation for calculation of gradients and Jacobians in Modern Control and Optimization, Machine Learning, Data Science, Loss Analysis and Estimations Theory is of paramount importance [1]. But it has been found that people from different fields use different conventions for computation without explicitly mentioning the underlying assumption and some of them those who do explain does not provide a way to comprehend other conventions for performing similar conventions. The diversity of single idea in multiple fields have been proven beneficial since the techniques developed for one type of problem may lead to solution of completely independent problem in other fields. Therefore, there must be a way to bridge links between very fundamental tools that are applied on day-to-day basis like vector differentiation one of the important tools. This article will provide a fundamental understanding of evaluation of multivariate derivatives. The two doctrines to evaluate derivatives will be explained. Finally, to have benefits of both worlds a fundamental framework will be discussed to go from one school of thought to another without loss of effective information.

Kronecker Product

The idea behind the evaluation and representation of derivatives is governed by the Kronecker Product (KP). The case for scalars is trivial, but for all other cases, this product helps to give a general notion for calculating derivatives in case of higher dimensions. Consider two matrices, A and B, of sizes $m \times n$ and $p \times q$ respectively. Where m, n, p, and q can assume any positive integer value. The Kronecker product C of two matrices having size mp x nq can be defined as follows:

$$\boldsymbol{C \triangleq A \otimes B} \tag{1}$$

$$C = \begin{bmatrix} a_{11}B & a_{12}B & \cdots & a_{1n}B \\ a_{21}B & a_{22}B & \cdots & a_{2n}B \\ \vdots & \vdots & \ddots & \vdots \\ a_{m1}B & a_{m2}B & \cdots & a_{mn}B \end{bmatrix}_{(mp\times nq)} \quad (2)$$

This product works for all combinations of scalars, vectors, and matrices.

Different Layouts used for Evaluating Partial Derivatives

The idea of layout depends on a specific application. In some applications, people want to carry out row perspective to extract valuable information because it closely resembles the single-dimension case with some exceptions. On the contrary, others want to use column pictures while evaluating derivatives. Treating a vector as a column vector has become an unofficial rule while working with most fields involving linear algebra as its computational engine, like gradient descent. There exist two layouts [2]:

- Numerator Layout
- Denominator Layout

a. Numerator Layout

Consider a function f such that $f: \mathbb{R}^p \to \mathbb{R}^q$, and x be a real object with dimensions m x n. The general case is addressed. However, x can be scalar, vector, or matrix. The numerator layout rule says to take $\frac{\partial}{\partial x}$ as transposed dimensions compared to the original as follows:

$$\frac{\partial}{\partial \mathbf{x}} = \begin{bmatrix} \frac{\partial}{\partial x_{11}} & \frac{\partial}{\partial x_{12}} & \cdots & \frac{\partial}{\partial x_{1m}} \\ \frac{\partial}{\partial x_{21}} & \frac{\partial}{\partial x_{22}} & \cdots & \frac{\partial}{\partial x_{2m}} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial}{\partial x_{n1}} & \frac{\partial}{\partial x_{n2}} & \cdots & \frac{\partial}{\partial x_{nm}} \end{bmatrix}_{(n\times m)} \quad (3)$$

The partial derivative matrix of order np x mq can now be evaluated by taking the KP of $\frac{\partial}{\partial x}$ and function f.

$$\frac{\partial \mathbf{f}}{\partial \mathbf{x}} = \frac{\partial}{\partial \mathbf{x}} \otimes \mathbf{f} = \begin{bmatrix} \frac{\partial \mathbf{f}}{\partial x_{11}} & \frac{\partial \mathbf{f}}{\partial x_{12}} & \cdots & \frac{\partial \mathbf{f}}{\partial x_{1m}} \\ \frac{\partial \mathbf{f}}{\partial x_{21}} & \frac{\partial \mathbf{f}}{\partial x_{22}} & \cdots & \frac{\partial \mathbf{f}}{\partial x_{2m}} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial \mathbf{f}}{\partial x_{n1}} & \frac{\partial \mathbf{f}}{\partial x_{n2}} & \cdots & \frac{\partial \mathbf{f}}{\partial x_{nm}} \end{bmatrix}_{(np\times mq)} \quad (4)$$

By using the above rule, one can determine the partial derivative for any combination of f and x *being scalar-scalar, scalar-vector, vector-scalar,* vector-vector, vector-matrix or matrix-vector and many other cases that may arise while working with derivatives in different applications.

Let us consider some examples.

Example 1: ***f(x)=x***

For x of size n x 1 . The partial derivative can be written as:

$$\frac{\partial \mathbf{x}}{\partial \mathbf{x}} = \begin{bmatrix} \frac{\partial \mathbf{x}}{\partial x_1} & \frac{\partial \mathbf{x}}{\partial x_2} & \cdots & \frac{\partial \mathbf{x}}{\partial x_n} \end{bmatrix} \quad (5)$$

$$\frac{\partial x}{\partial x} = \begin{bmatrix} \frac{\partial x_1}{\partial x_1} & \frac{\partial x_1}{\partial x_2} & \cdots & \frac{\partial x_n}{\partial x_n} \\ \frac{\partial x_2}{\partial x_1} & \frac{\partial x_2}{\partial x_2} & \cdots & \frac{\partial x_2}{\partial x_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial x_n}{\partial x_1} & \frac{\partial x_n}{\partial x_2} & \cdots & \frac{\partial x_n}{\partial x_n} \end{bmatrix}_{n\times n} = I_n \quad (6)$$

Example 2: ***f(x)=x^T A***

Another very important case that is encountered many times is $f = \mathbf{x}^\intercal \mathbf{A}$, where x has dimensions n x1 and A is a matrix of order n x m.

$$\frac{\partial \mathbf{x}^\intercal \mathbf{A}}{\partial \mathbf{x}} = \mathbf{A}^\intercal \quad (7)$$

<u>Note:</u> There is a very important consideration one needs to account for, which is the dimension of $\frac{\partial \mathbf{x}^\intercal \mathbf{A}}{\partial \mathbf{x}}$ is not $1\times nm$; rather, it is $m\times n$. This special case arises whenever the numerator becomes a row vector. In this case, the dimensions of the result are not dictated by the conventional KP rule, as was the case earlier. In all other cases, the dimension of the resultant partial derivative expression will be found using the KP product rule. This special case even leads to a shortcut method to evaluate partial derivatives whenever some expression involves the transpose of the variable present in the denominator. This shortcut states that whenever the numerator comes out to be a row vector, one should take the transpose of the whole numerator and then repeat the KP rule to find out the partial derivative.

$$\frac{\partial \mathbf{x}^\intercal \mathbf{A}}{\partial \mathbf{x}} = \frac{\partial}{\partial \mathbf{x}} \otimes \mathbf{x}^\intercal \mathbf{A} \quad = \text{row vector} \otimes \text{row vector} \quad (8)$$

$$\implies \quad \text{Transpose the numerator } \mathbf{x}^\intercal \mathbf{A} \quad (9)$$

$$\frac{\partial \mathbf{A}^\intercal \mathbf{x}}{\partial \mathbf{x}} = \mathbf{A}^\intercal \frac{\partial \mathbf{x}}{\partial \mathbf{x}} = \mathbf{A}^\intercal \quad (10)$$

Example 3: ***f(x)=x^T Ax***

$$\frac{\partial \mathbf{x}^\intercal \mathbf{A}\mathbf{x}}{\partial \mathbf{x}} = \frac{\partial \mathbf{x}^\intercal}{\partial \mathbf{x}}\mathbf{A}\mathbf{x} + \mathbf{x}^\intercal \mathbf{A}\frac{\partial \mathbf{x}}{\partial \mathbf{x}} \quad (11)$$

$\frac{\partial \mathbf{x}^\intercal}{\partial \mathbf{x}}$ is a row vector (12)

$\Longrightarrow$ Take the transpose of the whole numerator (13)

$$\frac{\partial \mathbf{x}^\intercal \mathbf{A}\mathbf{x}}{\partial \mathbf{x}} = \mathbf{x}^\intercal \mathbf{A}^\intercal \frac{\partial \mathbf{x}}{\partial \mathbf{x}} + \mathbf{x}^\intercal \mathbf{A} = \mathbf{x}^\intercal \mathbf{A}^\intercal + \mathbf{x}^\intercal \mathbf{A} \quad (14)$$

a. Denominator Layout

The denominator layout is just the transposed version of the Numerator Layout. However, to make it absolutely clear for readers, this layout will also be discussed in detail. Consider a function f such that $f: \mathbb{R}^p \to \mathbb{R}^q$, and x be a real object with m x n dimensions . The denominator layout rule says to take $\frac{\partial}{\partial x}$ as a matrix of partial derivatives with the same dimensions as x. This time, has to be transposed.

$$\frac{\partial}{\partial \mathbf{x}} = \begin{bmatrix} \frac{\partial}{\partial x_{11}} & \frac{\partial}{\partial x_{12}} & \cdots & \frac{\partial}{\partial x_{1n}} \\ \frac{\partial}{\partial x_{21}} & \frac{\partial}{\partial x_{22}} & \cdots & \frac{\partial}{\partial x_{2n}} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial}{\partial x_{m1}} & \frac{\partial}{\partial x_{m2}} & \cdots & \frac{\partial}{\partial x_{mn}} \end{bmatrix}_{(m \times n)} \quad (15)$$

The partial derivative matrix can now be evaluated by taking the KP of $\frac{\partial}{\partial x}$ and function f^T.

$$\frac{\partial \mathbf{f}}{\partial \mathbf{x}} = \frac{\partial}{\partial \mathbf{x}} \otimes \mathbf{f}^\intercal = \begin{bmatrix} \frac{\partial \mathbf{f}^\intercal}{\partial x_{11}} & \frac{\partial \mathbf{f}^\intercal}{\partial x_{12}} & \cdots & \frac{\partial \mathbf{f}^\intercal}{\partial x_{1m}} \\ \frac{\partial \mathbf{f}^\intercal}{\partial x_{21}} & \frac{\partial \mathbf{f}^\intercal}{\partial x_{22}} & \cdots & \frac{\partial \mathbf{f}^\intercal}{\partial x_{2m}} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial \mathbf{f}^\intercal}{\partial x_{n1}} & \frac{\partial \mathbf{f}^\intercal}{\partial x_{n2}} & \cdots & \frac{\partial \mathbf{f}^\intercal}{\partial x_{nm}} \end{bmatrix}_{(mq \times np)} \quad (16)$$

By using the above rule, one can determine the partial derivative using the denominator layout. Some examples that were considered for the numerator layout can be carried out as follows using the denominator layout:

Example 1: $f(x)=x$

For x of size n x 1 . The partial derivative can be written as

$$\frac{\partial \mathbf{x}}{\partial \mathbf{x}} = \begin{bmatrix} \frac{\partial \mathbf{x}^\intercal}{\partial x_1} \\ \frac{\partial \mathbf{x}^\intercal}{\partial x_2} \\ \vdots \\ \frac{\partial \mathbf{x}^\intercal}{\partial x_n} \end{bmatrix} \quad (17)$$

$$\frac{\partial x}{\partial x} = \begin{bmatrix} \frac{\partial x_1}{\partial x_1} & \frac{\partial x_2}{\partial x_1} & \cdots & \frac{\partial x_n}{\partial x_1} \\ \frac{\partial x_1}{\partial x_2} & \frac{\partial x_2}{\partial x_2} & \cdots & \frac{\partial x_n}{\partial x_2} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{\partial x_1}{\partial x_n} & \frac{\partial x_2}{\partial x_n} & \cdots & \frac{\partial x_n}{\partial x_n} \end{bmatrix}_{n \times n} = I_n \quad (18)$$

Example 2: $f(x)=x^\intercal A$

This particular case gave rise to a special case in numerator layout. Similarly, it is also a special case with a denominator layout because

$\frac{\partial \mathbf{f}}{\partial \mathbf{x}} = \frac{\partial}{\partial \mathbf{x}} \otimes \mathbf{f}^\intercal$=column vector $\bigotimes$column vector (19)

In this case, the dimension of $\frac{\partial \mathbf{x}^\intercal \mathbf{A}}{\partial \mathbf{x}}$ using the KP rule comes out to be nm x 1 . But standard documents evaluate this partial derivative as follows:

$$\frac{\partial \mathbf{x}^\intercal \mathbf{A}}{\partial \mathbf{x}} = \mathbf{A} \quad (20)$$

In denominator layout, this special case arises whenever the numerator becomes a column vector after taking the transpose. The shortcut previously discussed can now be extended for the case of the denominator layout. This shortcut states that whenever the modified numerator (numerator after taking transpose) comes out to be a column vector, one should take another transpose of the numerator and then apply the KP rule to find out the partial derivative. As seen above, the modified numerator comes out to be a column vector; therefore, this partial derivative will be evaluated without taking the transpose of the original numerator.

$$\frac{\partial \mathbf{x}^\intercal \mathbf{A}}{\partial \mathbf{x}} = \frac{\partial \mathbf{x}^\intercal}{\partial \mathbf{x}}\mathbf{A} = \mathbf{I_n}\mathbf{A} \quad (21)$$

$$\frac{\partial \mathbf{x}^\intercal \mathbf{A}}{\partial \mathbf{x}} = \mathbf{A} \quad (22)$$

Example 3: $f(x)=x^\intercal Ax$

$$\frac{\partial \mathbf{x}^\intercal \mathbf{A}\mathbf{x}}{\partial \mathbf{x}} \triangleq \frac{\partial \mathbf{x}^\intercal \mathbf{A}^\intercal \mathbf{x}}{\partial \mathbf{x}} = \frac{\partial \mathbf{x}^\intercal}{\partial \mathbf{x}}\mathbf{A}^\intercal \mathbf{x} + \mathbf{x}^\intercal \mathbf{A}^\intercal \frac{\partial \mathbf{x}}{\partial \mathbf{x}} \quad (23)$$

Since, $\frac{\partial \mathbf{x}}{\partial \mathbf{x}}$ =column vector $\bigotimes$column vector (24)

$\Longrightarrow$ Take the transpose of the whole numerator (25)

$$\frac{\partial \mathbf{x}^\intercal \mathbf{A}\mathbf{x}}{\partial \mathbf{x}} = \frac{\partial \mathbf{x}^\intercal}{\partial \mathbf{x}}\mathbf{A}^\intercal \mathbf{x} + \frac{\partial \mathbf{x}^\intercal}{\partial \mathbf{x}}\mathbf{A}\mathbf{x} \quad (26)$$

$$\frac{\partial \mathbf{x}^\intercal \mathbf{A}\mathbf{x}}{\partial \mathbf{x}} = \mathbf{A}^\intercal \mathbf{x} + \mathbf{A}\mathbf{x} \quad (27)$$

Relation between Numerator and Denominator Layouts

By looking at the examples considered in both cases, one can easily infer that the denominator layout is just the transposed version of the numerator layout and vice versa. By this simple rule, people working with either of the layouts can easily switch to another layout without much hassle.

$$\text{Numerator Layout} \overset{T}{\rightleftharpoons} \text{Denominator Layout} \qquad (28)$$

Conclusion

In this tutorial, the most fundamental idea of partial derivatives for machine learning, optimization, and modern control has been clarified by discussing the recipe of two commonly used methods, i.e., Numerator layout where the numerator is kept fixed, and the denominator is transposed and denominator layout where the numerator is transposed but denominator maintains its original shape. One special case is discussed under each method where either both numerator and denominator become row vectors, or both become column vectors. A shortcut is also introduced to evaluate derivatives without much worrying because that special case is encountered very often while practicing in the field. Finally, a bridge between two layouts is discussed, which is simply the transpose relationship. By transposing one layout, one can easily get the other form. It is recommended to use the Denominator layout, especially for students who have just been exposed to these derivatives, because this layout closely resembles a one-dimensional case with minor differences.

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BOOK REVIEW: "BEYOND SILK ROUTES"

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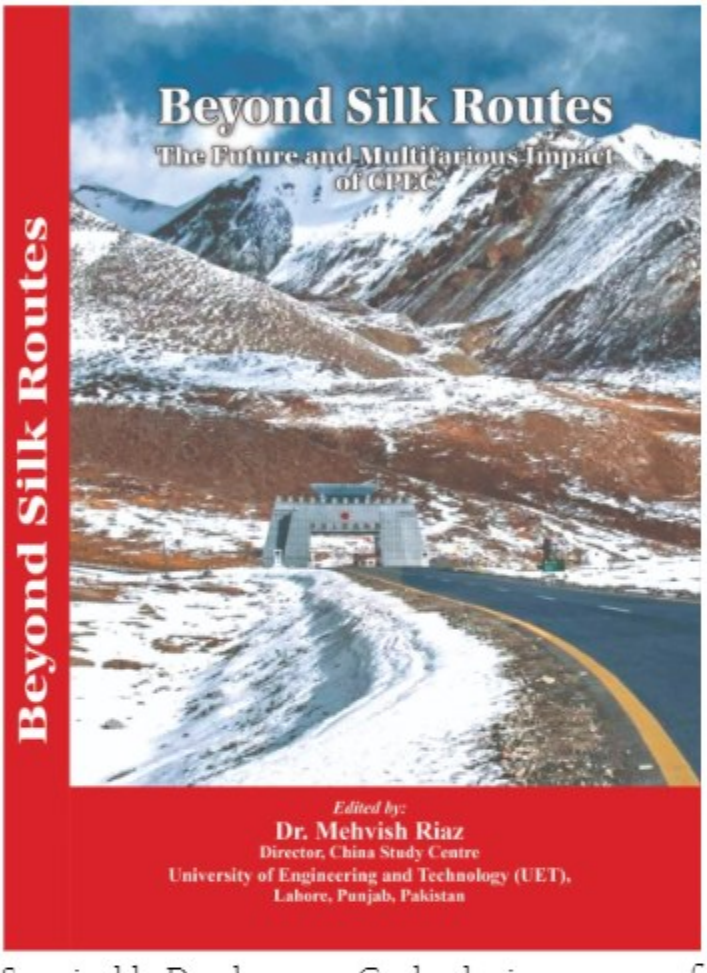
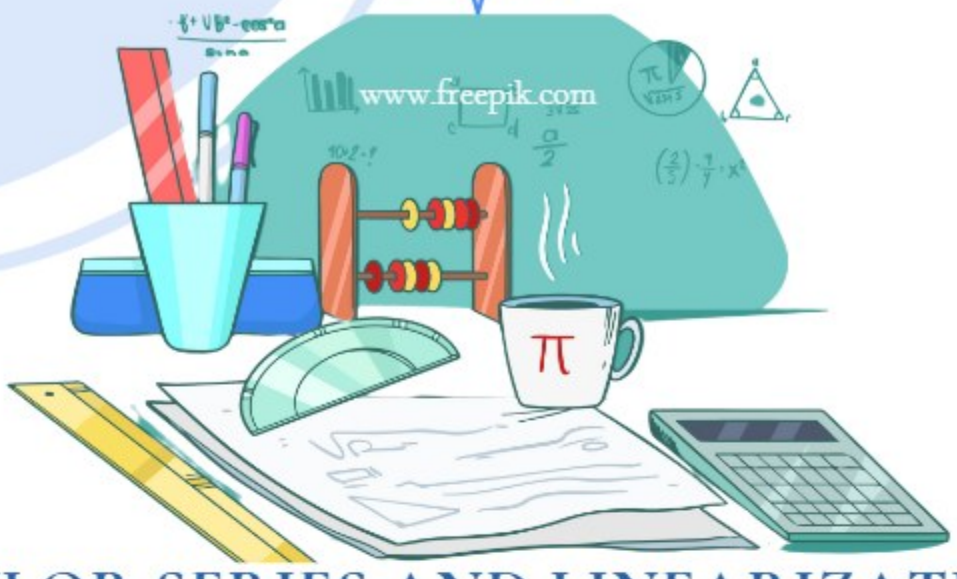
As we stand at the precipice of a new era defined by connectivity and collaboration, the China-Pakistan Economic Corridor (CPEC) emerges as one of the most ambitious and transformative infrastructure projects of the 21st century. CPEC has not only catalyzed economic development but has also strengthened the longstanding ties between Pakistan and China. This transformative initiative epitomizes the deep-rooted friendship and strategic partnership between our two nations.

In this context, I am pleased to introduce Beyond Silk Routes: The Future and Multifarious Impact of CPEC, a book published by China Study Centre, UET, Lahore with funding provided by the Higher Education Commission of Pakistan. The book highlights that through joint efforts, Pakistan and China have collaborated on mega-infrastructure projects, including highways, ports, railways, and digital infrastructure, laying the foundation for sustainable economic growth and regional connectivity. In the education sector, the role played by the Higher Education Commission of Pakistan as well as the China and Pakistan study centers established at different universities is noteworthy. The book, which consists of 12 chapters, encompasses topics, such the China Study Centre, UET, Lahore as a hub of cultural promotion, digital transformation in higher education resulting from the collaboration between IIOE-HEI and UET, Lahore, the social and infrastructural contribution made by the Orange Line Metro Transit System, the nexus of CPEC, SDGs and Higher Education, trade between Pakistan and China, defence diplomacy, cultural diplomacy, Chinese as a foreign language in Pakistan, properties of Port Qasim GPC, and diverse effects and issues concerning CPEC. The book offers a comprehensive exploration of the multifaceted impact of CPEC on Pakistan-China relations. The book explores various aspects of CPEC, including its impact on trade dynamics, educational cooperation, alignment with



Sustainable Development Goals, the importance of Chinese language proficiency, and the significance of energy and infrastructural projects, strengthening bilateral cooperation, and fostering mutual understanding between Pakistan and China. Furthermore, the book highlights the importance of sustained collaboration between government agencies, academia, civil society, and the private sector in realizing the shared vision of a prosperous and interconnected future. Let us reaffirm our commitment to deepening the Pakistan-China friendship and harnessing the full potential of CPEC for the benefit of our nations and region at large. I am profoundly grateful the authors, UET administrators, researchers, and contributors for their invaluable insights and efforts.



TAYLOR SERIES AND LINEARIZATION: APPLICATION PERSPECTIVE

By Dr. Muhammad Salman Fakhar (salmanfakhar@uet.edu.pk)

Abstract

In the matriculation and intermediate mathematics courses, students have discussed and learnt about Taylor Series expansion. While solving the questions related to Taylor Series expansion, the second and higher order terms are often neglected. The students get mastery at solving the questions, but they have never worked upon realizing that what was the need of this whole laborious effort of expanding a function around some point of interest on x-axis, and then neglecting the second and higher order polynomial terms. This article is a presentation of the importance of Taylor Series and especially, its utilization in linearization by discussing a few applications of engineering, to make students take interest in this wonderful mathematics concept. The article is a collection and organized presentation of the knowledge present in several books of applied mathematics, and engineering, in an easily understandable form.

Introduction

While having an experience of being a matriculation and then an intermediate level pre-engineering student about fifteen years ago, I had gone through studying mathematics course for four years. Now, being a faculty member at the top Engineering University, UET Lahore for last 9 years, I have been witnessing the students of my time and of now are having the ability to solve mathematical questions, but they are not able to link that knowledge with engineering applications. This is why some of them find it difficult to properly understand the mathematical and physical models of the engineering problems they deal with. The problem starts at the matriculation and intermediate level, where the students do have very good books in mathematics and the teachers are also very professional and awesome, but somehow, the students are unable to know, why a certain mathematical concept is being learnt. Being an engineering faculty member, or we can call it an applied mathematician also, I have found that there is a huge gap in students' understanding of the relatability of the general mathematical dimension being discussed with its application. I have, therefore, considered starting a series of articles, that may then lead to a compiled book of those articles, on understanding mathematics through applications, that are found in everyday life, or in literature on applied mathematics. These articles will help students, and maybe their teachers, to get familiarized with the wonderful phenomenon of applying mathematics, and the students will thus develop an interest in domains of mathematical applications, especially engineering, through mathematics itself.

One of the many awesome applications of mathematics, that are discussed in engineering problems is the application of the concept of linearization, extracted through the great Taylor Series Expansion. This article specifically intends to discuss the related concepts and discussions with the help of engineering applications.

Taylor Series and Linearization

By looking at the examples considered in both cases, one can easily infer that the denominator layout is just the transposed version of the numerator layout and vice versa. By this simple rule, people working with either of the layouts can easily switch to another layout without much hassle.

$$f(x) = f(a) + \frac{f'(a)}{1!}(x-a) + \frac{f''(a)}{2!}(x-a)^2 + \ldots + \frac{f^n(a)}{n!}(x-a)^n$$

Where, f(x) is the function of variable x. At some point of interest "a", where the "n" number of derivatives exist for that function (to understand this concept of the number of derivatives of a function, the concept of "continuity and existence of derivatives around a point of interest" maybe recalled from the Calculus books), the above equation is giving the expanded form of f(x) around that point "a" [1].

When students apply the Taylor series expansion formula for any function of interest around some point of interest, they often apply the next step of neglecting values for "order n = 2 and above" by applying the logic that the respective polynomial "P(x) for order n = 2 and above" becomes too small and approaching to zero. This logic of terms approaching zero is not applicable all the time. But, if only this logic is to be considered, even then, the purpose of neglecting higher order terms is not the same. Instead, the purpose is to estimate the function under consideration into an easier form, i.e., mostly the linear form. So it works like

- $f(x) = f(a)$ is the value of function at x = a
- $f(x) = f(a) + \frac{f'(a)}{1!}(x-a)$

is the first order polynomial, or the linear estimate of $f(x)$ around point a.

- $f(x) = f(a) + \frac{f'(a)}{1!}(x-a) + \frac{f''(a)}{2!}(x-a)^2$

is the second order polynomial, or the quadratic estimate of f(x) around point a.

Similarly, the estimate becomes better and closer in form to the original function $f(x)$ as the polynomials of higher order are kept on added [2].

It is usually cumbersome to solve the nonlinear functions and may require computer programs to solve them with the help of algorithms and numerical methods, because there is usually no analytical or exact solution. So, when analysis and design work is done in some engineering problem for their mathematical functions, it is always helpful to perform an estimated analysis based on utilizing the linear approximates of the nonlinear functions. This process of estimating a nonlinear function to its linear approximate around some point of interest "x = a" is called linearization [2]. And it offers many advantages by making analysis and design process easier.

Example of Linearization

Let us take the example of very famous exponential function e^x. The Taylor series expansion of the exponential function is given as

$$e^x = 1 + x + \frac{x^2}{2!} + \ldots + \frac{x^n}{n!}$$

Around a point x = a = 0 (we can therefore call it as Maclaurin Series also, that is the special case of Taylor Series of a function around x = a = 0), we draw the graphs of the actual function $f(x) = e^x$ and its first order, second order and fifth order polynomials. All the graphs are given in Figure 1, for the sake of comparison and understanding. We can see that, at point of interest x = a = 0, the Taylor series expansion gives the sum of polynomials. The first order polynomial, is just a straight line (linear) estimate of the function . The second order approximate is the better estimate to the original function and in this graph, the fifth order polynomial approximate is the nearest estimate of the original function. If we closely look at the graphs, the linear estimate serves the purpose of being a good estimate for the range of *"x less than or equal to 1.5"*. So, for the small range analysis, we can consider.

$$f(x) = e^x = 1 + x$$

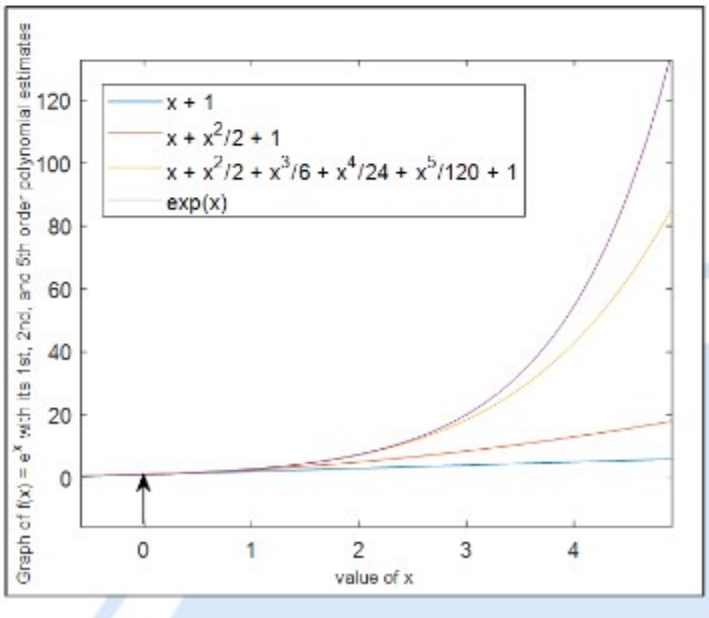


Figure 1. Graph of f(x) with its polynomial estimates

Examples in Engineering

There are so many engineering problems that incorporate nonlinear mathematical models, as observed in nature [3]. However, it is always handy to linearize these nonlinear functions, using the Taylor series expansions and ignoring the second and higher order terms. This is why, in matric and intermediate mathematics courses, the students are taught to neglect the second and higher order polynomials. A few examples are

Example 1 :

The current in the BJT (Bipolar Junction Transistor) is an exponential (nonlinear) function of the junction voltage. For small changes in junction voltage, the current can simply be related to the junction voltage with a linear function [4].

Example 2 :

The distance covered by the simple pendulum is the sinusoidal (nonlinear) function of the angle θ. For small changes in the angle θ, the sin (θ) can be equated to its first order approximate of sin (θ) = θ. So, the distance covered by the pendulum is simply taken equal to the angle θ, which is the linear approximate of the actual function [5].

Example 3 :

The heat capacity of gases is a quadratic (nonlinear) function of temperature. For small changes in temperature, the quadratic relation can be approximated to linear relation using the Taylor series expansion of the quadratic functions [6].
Considering it sufficient to explain our aim of the importance of Taylor Series, especially for the sake of linearization, in the real-world engineering applications.

Conclusion

Taylor Series is one of the many wonderful concepts in mathematics that find huge applications in the realm of engineering. Students of pre-engineering do know the methods of applying and solving the questions in their mathematics books using Taylor Series, but they do not know the reason and applications behind those procedures. This article was an attempt to familiarize the students with those knowledge gaps and to encourage them to understand the soul of any mathematical concept. This will help them become better mathematicians, especially the applied mathematicians and engineers.

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BOOK REVIEW: "FORBIDDEN CITY UNRAVELLED"

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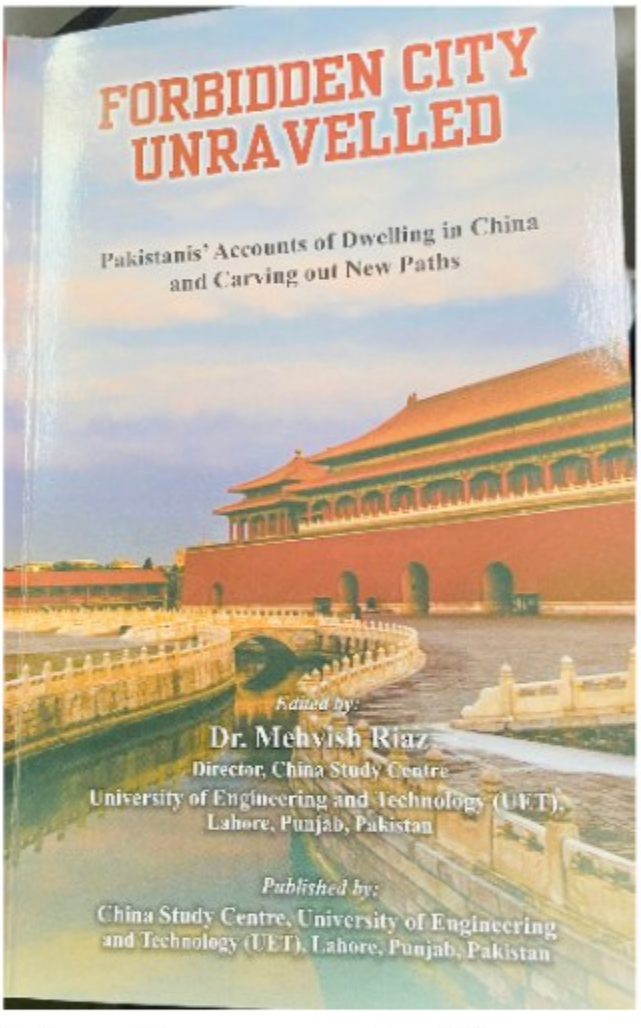
I am pleased to introduce the book titled, "Forbidden City Unravelled: Pakistanis' Accounts of Dwelling in China and Carving out New Paths" published by China Study Centre, UET, Lahore. The book highlights the experiences of Pakistani students and professionals during their visits to China. The book, which aims at developing an understanding of Chinese lifestyle, values, and landscape, takes the reader on an imaginative journey through the mysteries of Chinese alleys, institutions, and monuments imaginatively. As the authors experience the bustling streets of iconic Chinese cities, celebrate Chinese festivals, hike majestic mountains, and make achievements, the reader enjoys a blurring of boundaries and develops an appreciation for the authors' constructive endeavours. Unravelling the Forbidden City is akin to understanding and exploring China and availing opportunities for development. Overall, the book draws attention to the opportunities for tourism and collaboration between China and Pakistan. The tourism partnership between China and Pakistan holds immense potential for education, economy, and cultural enrichment. Pakistan is a land of adventure and travel, owing to its diverse landscape, majestic mountains, beautiful valleys, rich cultural heritage, and UNESCO world heritage sites. It boasts some of the world's highest and most spectacular mountain ranges, including the Himalayas, the Karakoram Range, and the Hindu Kush, offering breathtaking scenery and opportunities for mountaineering, trekking, and skiing. Famous peaks like K2 attract climbers and adventurers from around the globe. From white-water rafting in the Indus River to exploring historical landmarks like the ancient city of Mohenjo-Daro, the archaeological ruins of Taxila, the Buddhist remains of Takht-i-Bahi, and Lahore Fort, travelers from China and the rest of the world can immerse themselves in the country's vibrant culture and history.



The publication of this book serves as a testament of the enduring spirit of collaboration and partnership that defines the relationship between Pakistan and China. Moreover, the authors' journeys, including those of UET alumni and faculty members, exemplify the exceptional capabilities, resilience, and unwavering determination of Pakistani students and professionals. The book reflects their academic and professional journeys, revealing their ability to overcome challenges and adapt to diverse environments. Through their stories, the book emphasizes the resourcefulness and innovative spirit that define these individuals, illustrating how they continuously strive for excellence and make significant contributions in their respective fields.

DESIGN AND DEVELOPMENT OF CARDIAC MONITORING SYSTEM

By Usama Tahir (usamatahir2@gmail.com)

Abstract

cardiovascular disease is one of the top causes of mortality globally. With the introduction of sophisticated signal processing and computer technology, techniques for the automated detection of cardiac disorders using ECG have emerged as one of the most promising tactics in clinical decision support systems. A system like this can give a rapid, accurate, and reliable diagnosis for a variety of cardiac problems, as well as reduce the workload for cardiac experts and allow for the monitoring of several patients at the same time. Techniques for automated ECG processing and analysis are established in this work. Each patient's raw ECG signal is processed via a variety of filters that may be used to minimize noise and improve the quality of the ECG signal. Among the filters used are band-pass filters. The feature extraction step in this approach is when a number of characteristics based on medical data are extracted from the plain signal in order to
discover peaks and waves. A classification stage is developed for diagnosis purposes utilizing the classification methods to improve accuracy: Rule-based system and Deep Artificial Neural Network system. Based on medical values and borderlines, the threshold values classification approach is effective. A warning notice with the predicted heart illness flashed if any characteristic went over or beyond specified levels. The second categorization method uses Deep Artificial Neural Network trained system which validates the results predicted by developed ECG monitoring system.

Methodology

The system architecture consists of hardware setup having ECG sensor and micro controller. Developing the hardware setup for a Cardiac Monitoring System using the AD8232

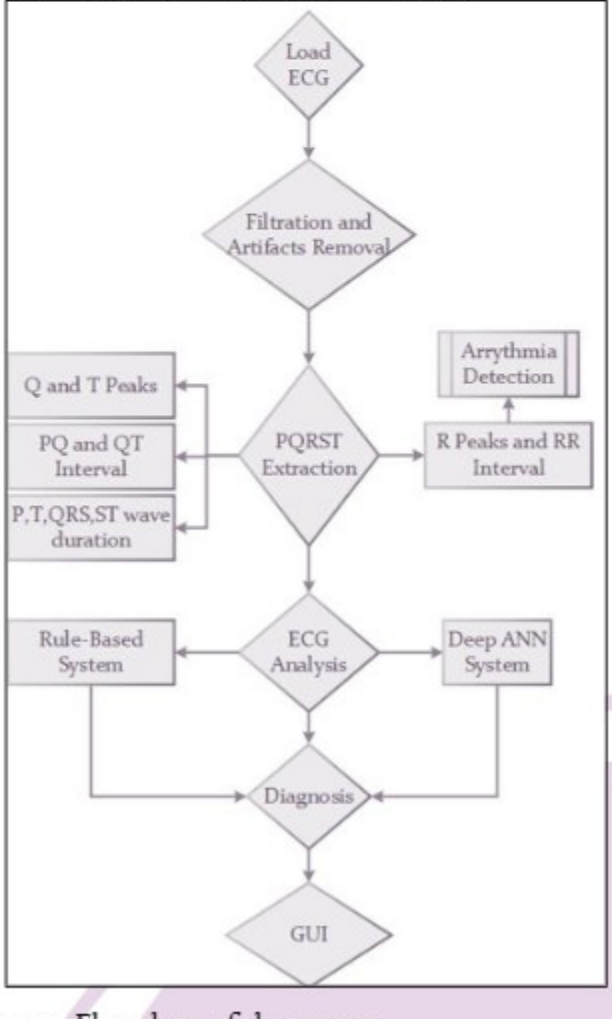


Figure 1. Flowchart of the system

sensor involves carefully selecting and configuring components to ensure accurate ECG signal acquisition and processing. A model with three electrodes and specialized sensors labelled RA (red) for right arm, LA (yellow) for left arm, and RL (green) for right leg is used to capture the ECG signal from the volunteer. Apply the electrode patch to the prepared skin area. To achieve appropriate skin contact, smooth the electrode patch down in a circular motion. Pushing down directly on the contact gel medium with soft gel electrodes may displace the gel and generate monitoring artifacts. Figure 2 shows hardware setup. When utilizing firm gel electrodes, it is suggested that the centre of the electrode be slightly pushed against the skin during application to achieve direct contact. By using the above setup, the ECG data has been collected.

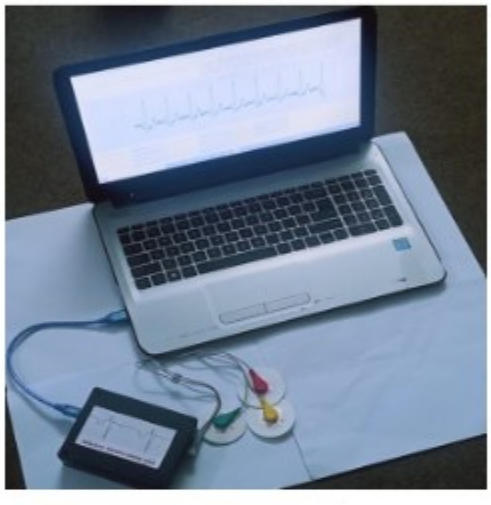


Figure 2. Interfacing of AD8232 and Microcontroller

The data has been taken from different subjects of different groups. The duration for collection of ECG sample is 30 seconds. Figure 3 shows the position of ECG electrodes for collection of ECG sample.

Sample has been collected in different scenarios e.g.

- When subject is at Rest
- After Workout
- After walk

In this study, ECG data is acquired using the AD8232 sensor, and subsequent signal processing is performed using the NeuroKit 2 library in Python. Now, Implementing a bandpass filtering technique on an electrocardiogram (ECG) signal in Python. The filter used is a Butterworth filter, known for its smooth frequency response. Figure 4 shows the real-time ECG signal before applying filtration. The lower and upper cut-off frequencies for the bandpass filter are set to 5 Hz and 50 Hz, respectively. Before designing the filter, the cut-off frequencies are normalized with respect to the

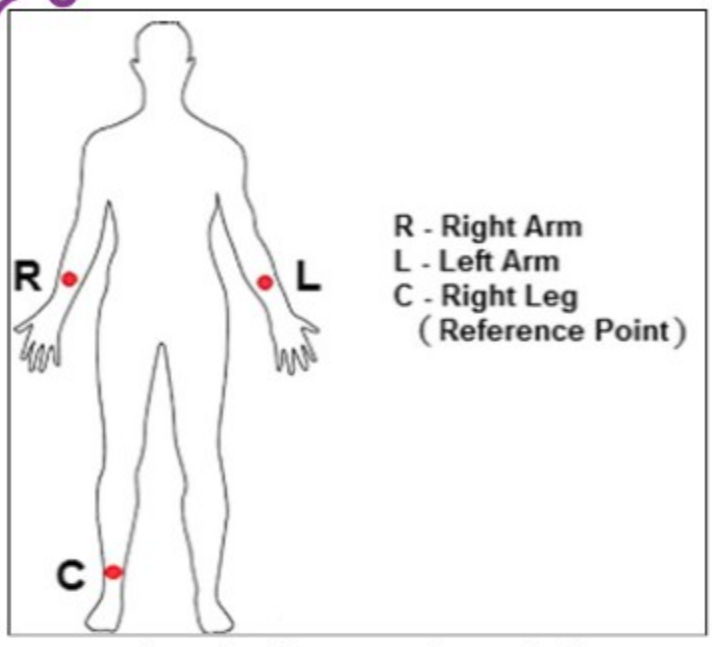


Figure 3. Electrodes placement in human body

Nyquist frequency, which is half of the sampling rate.

The Butterworth filter of order 1 (first order) is then designed using the normalized cut-off frequencies. Finally, the filtfilt function from the SciPy. Signal module is applied to the ECG signal using the designed filter coefficients, resulting in a filtered ECG signal that retains frequencies in the specified band (5 Hz to 50 Hz). The bandpass filtering is commonly employed in bio signal processing to remove unwanted noise and focus on the relevant frequency range for ECG analysis [16].

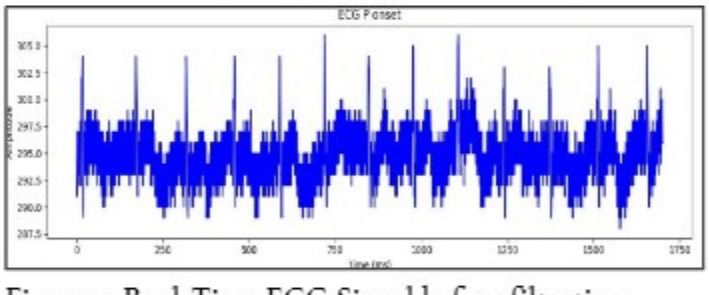


Figure 4. Real-Time ECG Signal before filtration

Normalization on an electrocardiogram (ECG) signal, a common pre-processing step in signal processing and data analysis. The goal is to rescale the signal values between 0 and 1, making the signal more amenable for certain algorithms and facilitating comparisons between signals. The process involves subtracting the minimum value of the original ECG signal from each data point, shifting the entire signal upward, and then dividing the result by the range of the original signal (the difference between its maximum and minimum values). This operation ensures that the normalized signal retains the relative proportions of values within the original signal while being constrained to the [0, 1] range. Figure 5 shows the filtration and

normalization of raw ECG signal.

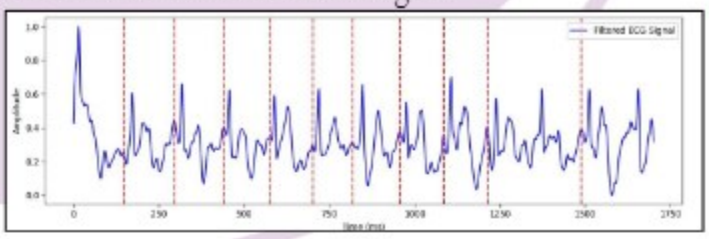


Figure 5. Filtered and Normalized ECG

In ECG signal, the main parameters are PQRST. If the time domain parameters of PQRST are known then the cardiac risk can be identified. So here the time intervals of different segments e.g., QRS segment, ST Segment and R Peaks are to be extracted to identify cardiac state as number of risks depend upon these parameters. Other than this the statistical analysis will be performed on ECG signal to determine Heart Rate Variability risks. To perform various analyses on an electrocardiogram (ECG) signal, it is needed to extract and present key intervals. Firstly, it calculates and prints the PR intervals along with their mean value, checking for the presence of values in the given list. Next, it computes the durations of QRS complexes, filters out any Nan values, calculates the mean duration, and displays the result in a message box. Finally, focusing on the ST segment calculates its durations, filters out Nan values, computes the mean duration, and displays the result in another message box. The inclusion of error handling for Nan values enhances the robustness of the analysis, ensuring accurate and meaningful results [17]. SciPy library, is used to detect peaks in the filtered ECG signal. The height parameter sets a threshold for peak detection, and distance sets the minimum distance between peaks. Calculating RR intervals by taking the difference between consecutive R-peaks and dividing by the sampling frequency (fs). The heart rate is then computed in beats per minute (BPM) by taking the inverse of the mean RR interval. Extracting ST segments around the R-peaks. It defines a duration (st-segment-duration) and then iterates through each R-peak to extract the corresponding segment from the filtered ECG signal. Figure 6 shows PQRST detection.

Heart Rate Variability (HRV) is a measure of the variation in time between successive heartbeats. It is an essential aspect of cardiovascular health and reflects the dynamic interplay between the sympathetic and parasympathetic branches of the autonomic nervous system (ANS).

In the signal analysis component, the analysis is performed on the basis of the parameters extracted.

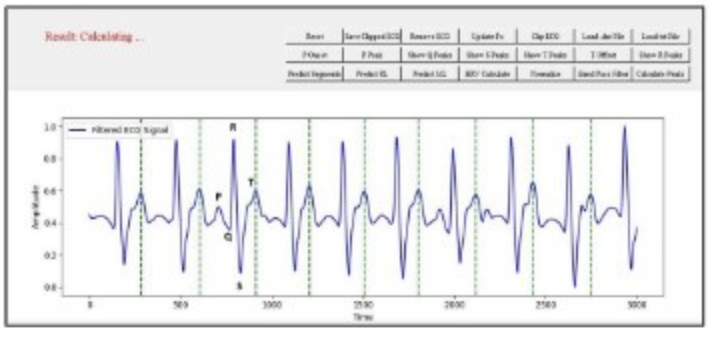


Figure 6. PQRST Detection

After analysing the parameters, the decision is made that what kind of cardiac risks are present and the subject will be classified as healthy or unhealthy [21]. In the rule-based system, there are the specific rules for ECG monitoring provided in different medical books. It is analysed that PQRST wave is lying in normal duration or not, on this basis, the ECG signal is classified [20]. In the development of a Cardiac Monitoring System, a Residual Neural Network (ResNet) model with 34 layers and 16 convolutional layers, named" ResNet-30s-34lay-16conv.hdf5," has been employed for ECG signal classification. The system validates its results using this pre-trained deep learning model, aiming to categorize ECG signals into noisy, Atrial Fibrillation disease, and Normal states. The input data for classification has a duration of 30 seconds. Through this validation process, the Cardiac Monitoring System ensures the accuracy and reliability of its ECG signal classifications, providing a robust and trustworthy platform for cardiac health monitoring. Classes:

1. Noisy data
2. Atrial fibrillation
3. Normal data

Results

This section presents the outcomes of the electrocardiogram (ECG) analysis conducted to investigate cardiac disorders. The findings are organized to address key aspects of the ECG signal,

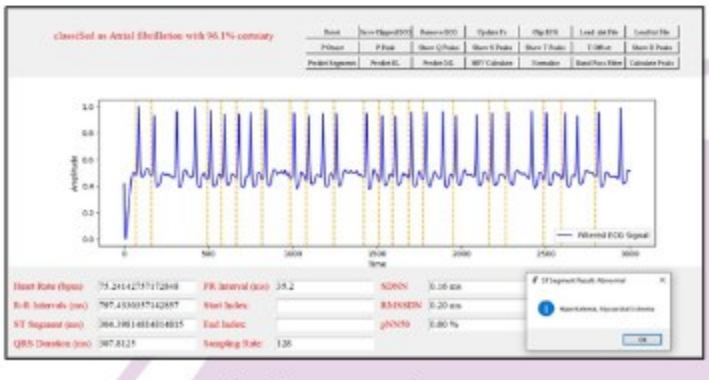


Figure 7. Atrial Fibrillation Prediction

including signal characteristics, PQRST detection, heart rate variability (HRV), statistical comparisons, and the identification of any abnormalities or anomalies. Figure 7 shows the analysis of the ECG signal, taken from a dataset of patients suffering from Atrial Fibrillation. The ECG data is collected from a dataset of subjects with disease of atrial fibrillation, which is also predicted by designed system as shown in results. Figure 9 shows the analysis of the ECG signal, taken from a dataset of patients suffering from Myocardial Ischemia.

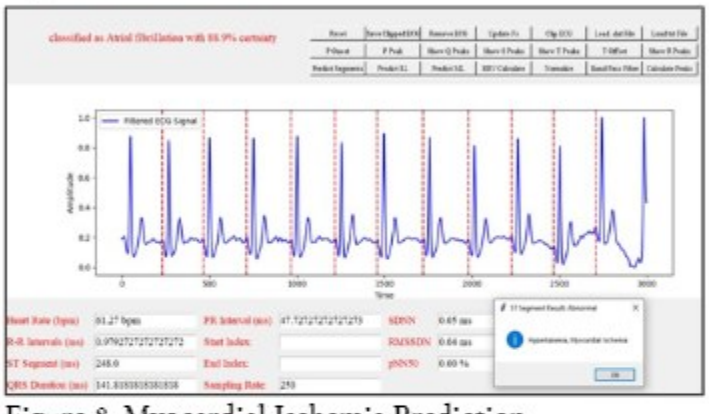


Figure 8. Myocardial Ischemia Prediction

Conclusion and Future Work

An effective method for detecting a variety of cardiac disorders in real time is presented by analysing PQRST waveforms. This technology has enormous potential for enhancing patient care, enabling remote monitoring, and assisting in the early identification and intervention of heart disorders, eventually leading to improved healthcare outcomes. The research on cardiac monitoring opens up several exciting avenues for future exploration and development. Here are some potential future directions for this research: Develop wearable or implantable devices that can provide continuous, long-term cardiac monitoring. This would enable the detection of chronic conditions and trends in cardiac health over extended periods. Continue research into cost-effective solutions to make cardiac monitoring more accessible, especially in resource-constrained healthcare environments. Explore the possibility of real-time interventions based on detected abnormalities. This might involve automated drug delivery or non-invasive stimulation to stabilize heart rhythms. Future research in these directions has the potential to revolutionize cardiac healthcare, offering improved diagnostics, personalized treatment plans, and better outcomes for patients with cardiac conditions. Collaboration between researchers, clinicians, and technology developers will be crucial in advancing these innovations.

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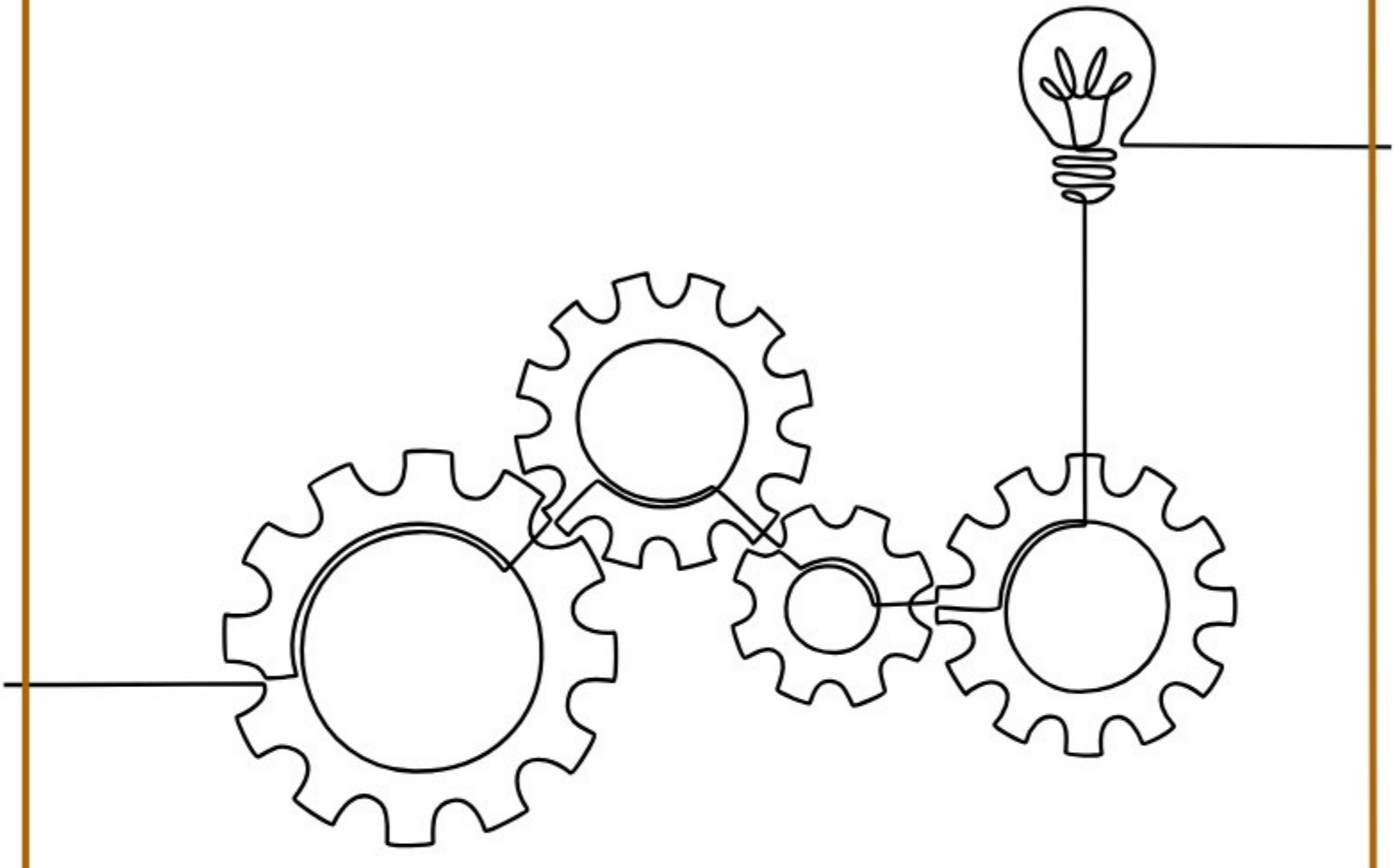
سُوْرَةُ الحَدِيد

لَقَدْ اَرْسَلْنَا رُسُلَنَا بِالْبَيِّنٰتِ وَاَنْزَلْنَا مَعَهُمُ الْكِتٰبَ
وَالْمِيْزَانَ لِيَقُوْمَ النَّاسُ بِالْقِسْطِ ۚ وَاَنْزَلْنَا الْحَدِيْدَ فِيْهِ
بَاْسٌ شَدِيْدٌ وَّمَنَافِعُ لِلنَّاسِ وَلِيَعْلَمَ اللّٰهُ مَنْ يَّنْصُرُهٗ وَ
رُسُلَهٗ بِالْغَيْبِ ۭ اِنَّ اللّٰهَ قَوِيٌّ عَزِيْزٌ ﴿۲۵﴾

Indeed, We sent Our messengers with clear proofs, and with them We sent down the Scripture and the balance ˹of justice˺ so that people may administer justice. And We sent down iron with its great might, benefits for humanity, and means for Allah to prove who ˹is willing to˺ stand up for Him and His messengers without seeing Him. Surely Allah is All-Powerful, Almighty.

Al-Quran [57: 25]



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