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INNOVATIVE APPROACHES IN SCIENCE & TECHNOLOGY RESEARCH VOLUME IV

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PREFACE

Science and technology have always played pivotal roles in the advancement of human civilization. As we move deeper into the 21st century, innovation within these fields is accelerating at an unprecedented pace. The ability to integrate new techniques, methodologies, and interdisciplinary approaches has become essential for pushing the boundaries of knowledge and solving complex global challenges. This book, Innovative Approaches in Science and Technology Research, highlights some of the most groundbreaking advancements that reflect the transformative power of modern science and technology.

In today's era, research is no longer confined by traditional boundaries. From biotechnology and nanotechnology to advanced computing and materials science, the convergence of disciplines is leading to a renaissance in research and development. This volume showcases the innovative approaches being employed across a variety of scientific fields, emphasizing the importance of creativity and collaboration in driving forward research that can address real-world problems. By exploring these cutting-edge methodologies, we aim to inspire both current and future researchers to think beyond conventional paradigms and embrace new techniques that can yield transformative results.

The chapters in this book cover a diverse range of topics, each contributing to the overarching theme of innovation. Whether it's harnessing the power of artificial intelligence for data analysis, employing nanomaterials for environmental applications, or advancing the understanding of biological systems through molecular techniques, the research presented here demonstrates how novel approaches are reshaping the landscape of science and technology.

We hope this book serves as both an inspiration and a resource for scientists, engineers, and technologists, encouraging them to adopt innovative approaches in their own work. By embracing the spirit of innovation, we can collectively unlock new possibilities and create a brighter, more advanced future for all.

Editors

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GM MUSTARD IN INDIA: A STEP TOWARDS SUSTAINABLE OILSEED PRODUCTION

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1. Introduction:

One of the most significant oilseed crops in India is mustard (*Brassica juncea*), which is used extensively as a condiment and for its oil. Despite its importance, low yields and pest and disease susceptibility are problems in India's mustard cultivation. Scientists have created genetically modified (GM) mustard in order to address these problems. The goals of genetically modified mustard are to boost the oilseed sector, increase productivity, and lessen reliance on imports. On October 25, 2022, the Ministry of Environment, Forests, and Climate Change (MoEFCC), Government of India, authorized the environmental release of hybrid seed production technology in mustard that uses genetic engineering techniques (often referred to as GM mustard). For a total of Rs. 1,56,800 crores, India purchased 14.1 million tonnes of edible oils in 2021–2022. The cost of importing edible oil in 2022–2023 has risen to Rs. 1,67,270 crores. Therefore, increasing the output of crops used to make edible oil is essential. There has been much discussion surrounding the creation and acceptance of genetically modified mustard in India, with issues pertaining to farmers' rights, safety and the environment. The science, advantages, debates and present state of genetically modified mustard in India are examined in this chapter.

2. Background on Mustard Cultivation in India

One of the biggest producers of mustard is India, where it is mostly grown in the states of Madhya Pradesh, Uttar Pradesh, Punjab, Rajasthan, and Haryana. In Indian cooking, mustard oil is a basic ingredient, and mustard seeds are utilized in a variety of dishes. However, because of inadequate indigenous production, India imports a sizable amount of edible oil. This reliance can be lessened by increasing mustard yield. Mustard yields have not been considerably increased by conventional breeding techniques. As a result, researchers are looking into genetic modification as a possible remedy.

3. Development of Genetically Modified Mustard

- **What is GM Mustard?**

GM mustard, more especially the DMH-11 (Dhara Mustard Hybrid-11) hybrid, was created by the University of Delhi's Centre for Genetic Manipulation of Crop Plants (CGMCP). The primary goal was to develop a hybrid that, in comparison to conventional types, could greatly boost mustard output. The term "GM mustard hybrid technology" describes the process of creating mustard hybrids with the *barnase-barstar* gene system through genetic engineering.

The majority of mustard is a self-pollinating crop. Fertility restorer (RF) lines with the *barstar* gene are crossed with male sterile (MS) lines with the *barnase* gene to enable cross-pollination and create hybrid seeds between two distinct parental lines. The bar gene, which gives resistance to the herbicide phosphinothricin, is also present in the *barnase* and *barstar* lines. The development of lines bearing the *barnase* and *barstar* genes, as well as the creation of hybrid seeds, depend on the bar gene [1].

- **How is GM Mustard Developed?**

The development of GM mustard involves two important genes from *Bacillus amyloliquefaciens*:

- **Barnase:** This gene is introduced into the male parent line to make it male-sterile (unable to produce pollen).
- **Barstar:** This gene is introduced into the female parent line to restore fertility when crossed with the male line.

Scientists can produce hybrid types with higher production potential by utilizing these genes. Furthermore, GM mustard is designed to withstand herbicides, which facilitates weed control.

The University of Delhi South Campus in New Delhi is home to the Centre for Genetic Manipulation of Crop Plants (CGMCP), which has created the two parent lines, EH-2 (Early Heera-2) modbs 2.99 (RF line) and Varuna bn 3.6 (MS line), as well as their hybrid DMH-11, which uses *barnase barstar* technology. A group headed by renowned geneticist and former University of Delhi Vice Chancellor Prof. Deepak Pental created the two parental lines and hybrid DMH-11 with funding from the National Dairy Development Board (NDDB) and the Department of Biotechnology (DBT). The Biotechnology Industry Research Assistance Council (BIRAC) provided support for the biosafety assessment of the first hybrid DMH-11 and the GM parental lines. The Government of India owns all of the funding organizations [1].

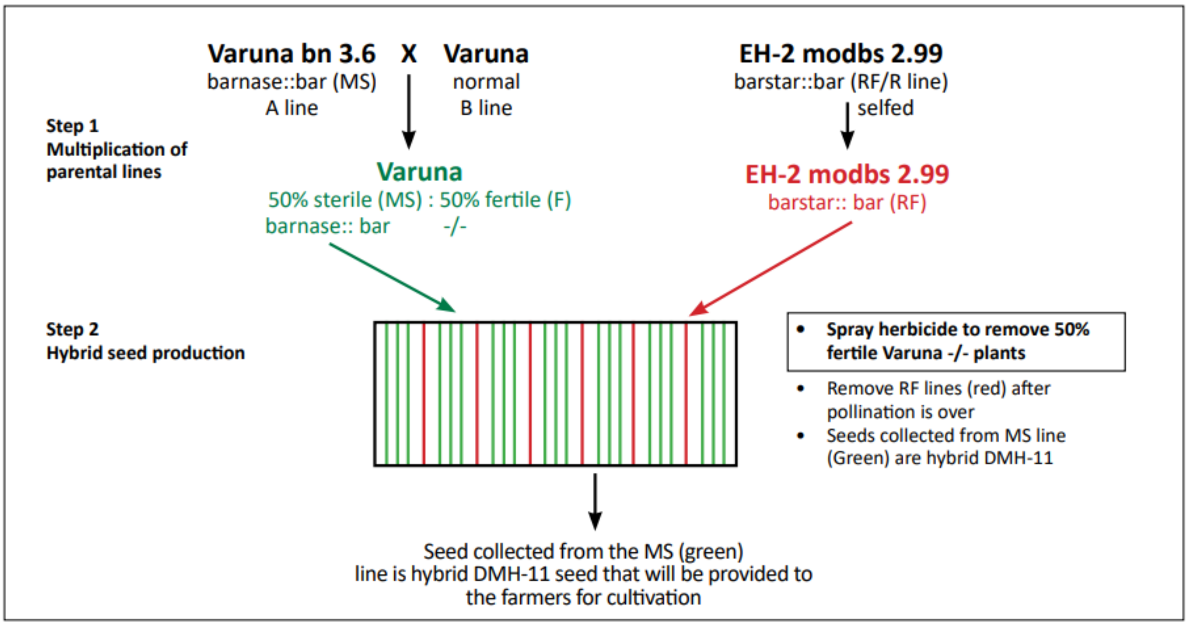

Figure 1: Hybrid seeds produced with the *barnase - barstar* system [1]

- **DMH-11 is a herbicide-tolerant crop**

The concealed herbicide tolerance (HT) trait mentioned above is without a doubt the primary source of contention surrounding GM mustard. According to its creators, DMH-11 was not intended to be HT. Nonetheless, the Genetic Engineering Appraisal Committee (GEAC) released a letter last October authorizing its release, which unequivocally states that DMH-11's genetic composition and both parental lines possess the bar gene, demonstrating the presence of herbicide tolerance. The clearance letter also stipulated that under no circumstances would any type of herbicide be used in the field to grow the genetically modified mustard, and that any use of herbicide without the required approval would be subject to the appropriate legal action. This criterion alone shows that the GM appraisal committee is well aware of the herbicide resistance of this GM mustard and the likelihood of herbicide use in farmers' crops [2].

- **Hybrid Vigour and Yield Improvement**

Because mustard plants self-pollinate, it is challenging to create hybrids through standard mustard breeding. Higher yields are produced by hybrids that display "heterosis" or hybrid vigour thanks to GM technology. According to reports, DMH-11 offers a 25–30% yield boost over current types [6].

Multi-location trials at the end of the lengthy list of field trials showed consistently better yields than both the parents and local comparators (Table 1). A number of field trials were conducted in order to develop the transgenic DMH-11 hybrid. Confined field trials began in 2004, followed by multi-location trials in 2006–07, biosafety research level (BRL I) trials (2010–11 and 2011–12), and BRL II trials (2014–15) at different locations. Results from the three BRL trials in eight locations were combined, and the yield gains over the national check variety were 37%. Additionally, the GM mustard hybrid produced more than Varuna bn3.6 and EH-2 modbs2.99, the parental lines. The key to attaining hybrid vigour or heterosis was that the resulting hybrid (DMH-11) produced more than either of its parents. This discovery served as proof of concept that the transgenic technology-based seed production system produced heterotic yield seeds with hybrid vigour [7].

Table 1: Biosafety Research Level- I (BRL-I) and BRL-II Trials and Yield Gains in Different Locations for DMH-11 Hybrid vis-à-vis National Check and Parental Lines

(kilograms per ha)

Trials	Locations/Mean Yield	DMH-11 Hybrid	National Check Variety (Maya/ RL-1359)	Parental Lines	
				Varuna	EH-2
BRL-I trials in the first year (2010–11)	Kumher	2,285	2,057	1,866	1,793
	Naugaon	2,515	1,767	1,741	1,716
	Sri Ganganagar	3,000	2,287	2,670	2,182
	Mean yield	2,600	2,037	2,093	1,897
BRL-I trials in the second year (2011–12)	Kumher	2,892	2,195	2,375	1,873
	Naugaon	3,157	1,836	2,169	1,608
	Mean yield	3,025	2,016	2,272	1,741
BRL-II trials in 2014–15	Ludhiana	2,543	1,965	2,006	1,740
	Bhatinda	2,734	1,792	1,911	1,443
	IARI, New Delhi	1,879	1,571	1,746	953
	Mean yield	2,386	1,776	1,887	1,378

(1) BRL-I was conducted at three locations during 2010–11 and 2011–12 at Krishi Vigyan Kendra (KVK) at Kumher, Bharatpur, Rajasthan; Agricultural Research Station, Naugaon, Alwar, Rajasthan; and Agricultural Research Station, Sri Ganganagar, Rajasthan.

(2) BRL-II was conducted at three locations during 2014–15 at the Indian Agricultural Research Institute (IARI), New Delhi; Punjab Agricultural University (PAU), Ludhiana, Punjab; and Regional Research Station (RRS), PAU, Bathinda, Punjab. The field trial at

Sri Ganganagar was discontinued prematurely (two weeks before harvest) in the CBRL I, second season trial.

(3) The trials were conducted under the overall guidance and supervision of the National Directorate of Rapeseed and Mustard, Indian Council of Agricultural Research, New Delhi.

(4) RL-1359 was the national check for mustard varieties/hybrids at the time of trial. Varuna and EH-2 were the parental lines for DMH-11.

Sources: GEAC (2016): Assessment of Food and Environmental Safety (AFES) (2016) for Environmental release of Genetically Engineered Mustard (Brassica juncea) hybrid DMH-11 and use of parental events (Varuna bn3.6 and EH2 modbs2.99) for development of new-generation hybrids, Genetic Engineering Appraisal Committee, Ministry of Environment, Forest and Climate Change, Government of India, New Delhi [7].

4. Benefits of GM Mustard

- **Increased Yield**

The increased yield of GM mustard is its main advantage. By doing this, India may lessen its reliance on imported edible oils, saving money and assisting regional farmers.

- **Improved Oil Quality**

It is possible to modify genetically modified mustard to have better oil quality, such as reduced erucic acid content, which is deemed unsuitable for human consumption. Customers may choose healthier options as a result of improved oil quality.

The total edible oil demand of India was 24.6 million tonnes (2020-21) with domestic availability of 11.1 million tonnes (2020-21). In 2020-21, 13.45 million tonnes (54%) of the total edible oil demand was met through import worth about ₹1,15,000 crore, which included palm oil (57%), soybean oil (22%), sunflower oil (15%) and small quantity of canola quality mustard oil. In 2022-23, 155.33 lakh tonnes (55.76%) of the total edible oil demand was met through import [3, 4 & 5].

- **Better Weed Management**

Farmers can use particular pesticides to eradicate weeds without endangering the mustard crop thanks to the herbicide-tolerant feature. As a result, less hand weeding is required, which lowers labor costs and increases farm productivity.

- **Reduction in Pesticide Use**

Genetically modified technology may lessen the need for chemical pesticides by creating pest-resistant cultivars, which would save money and have a smaller negative impact on the environment.

5. Controversies and Concerns

In India, genetically modified mustard has been the subject of several debates despite its possible advantages. Numerous questions have been raised about its safety, effects on the environment, and socioeconomic implications.

- **Environmental Impact**

There are worries that transgenes could enter the environment as a result of GM mustard cross-pollinating with wild cousins. This could have an impact on biodiversity and result in the rise of "superweeds," which might be immune to regular herbicides.

- **Impact on Non-GM Mustard Varieties**

Concerns about how GM mustard might impact conventional mustard types and cause genetic contamination have been voiced by farmers and campaigners. Since mustard blooms are a significant source of nectar for honeybees, there is also concern that GM mustard may have an effect on the production of honey. Opponents contend that because GM mustard affects pollinators, its use could upset the ecology.

- **Food Safety**

One of the main concerns has been whether GM mustard is safe for human consumption. The long-term health repercussions of consuming items made from genetically modified mustard oil are questioned by some. The public is nevertheless concerned about the possible dangers of genetically modified foods despite the fact that thorough safety testing is carried out.

- **Farmer Dependency on Seed Companies**

Another significant worry is that farmers may become reliant on seed firms to buy new seeds every season as a result of the extensive usage of GM crops. Farmers may have to pay more as a result, and there are concerns that large companies may control the seed market and undermine farmer autonomy.

6. Regulatory Framework for GM Crops in India

- **Role of Genetic Engineering Appraisal Committee (GEAC)**

The primary regulatory agency in India in charge of authorizing the commercial release of genetically modified crops is the Genetic Engineering Appraisal Committee (GEAC). Prior to approving GM crops for field testing and commercial production, the committee evaluates the crops' safety, environmental impact, and economic feasibility.

- **Approval Process for GM Mustard**

Over ten years ago, the process of developing and approving genetically modified mustard got underway. The GEAC recommended in 2016 that DMH-11 be approved for

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commercial cultivation. However, a number of parties opposed the decision, which caused the final approval to be delayed. A final ruling regarding the commercial release of genetically modified mustard is still pending after the issue has been discussed in court.

- **Public Consultation and Stakeholder Engagement**

In India, stakeholders can voice their opinions on the implementation of GM technology during public consultations that are part of the clearance process for GM crops. Before a decision is taken, this helps to address public concerns and ensure transparency.

7. Current Status of GM Mustard in India

In India, GM mustard has not yet been made available for purchase. Arguments for and against its inclusion are being made by many parties, and the matter is still up for debate. Given the effects on farmers, the environment, and public health, the government has taken a careful approach. Before a decision is reached, more field testing and investigation could be required to address the issues brought up by detractors.

8. Future Prospects of GM Mustard

- **Need for Higher Edible Oil Production**

In the upcoming years, India's expanding need for edible oil is anticipated to rise. GM mustard has the potential to significantly contribute to the nation's oilseed supply if it can effectively overcome the problems of poor yield and high production costs. India can boost its agricultural industry and raise the standard of living for mustard farmers by lowering its reliance on imports.

- **Research and Innovation**

To create GM crops that are sustainable, safe, and effective, further research is required. Biotechnology advancements may result in the creation of genetically modified mustard cultivars with increased yields, higher disease and insect resistance, and improved nutritional qualities.

- **Balanced Approach to Regulation**

It will take a balanced regulatory strategy for GM mustard to be a practical choice. This entails conducting in-depth safety evaluations, interacting with the public to allay their worries, and giving farmers precise instructions. GM mustard has the potential to represent a major advancement in India's acceptance of agricultural biotechnology if certain prerequisites are satisfied.

Conclusion:

There is a chance to address some of the major issues facing India's agriculture industry with genetically modified mustard. GM mustard has the potential to improve oil quality, lower costs, and boost yields, which might benefit farmers' livelihoods and the nation's economy. Addressing the safety, socioeconomic, and environmental issues related to its adoption is essential, though. The safe and advantageous use of genetically modified mustard in India may be made possible by a careful, open, and science-based regulatory approach.

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CUTTING-EDGE TECHNOLOGY FROM TESLA

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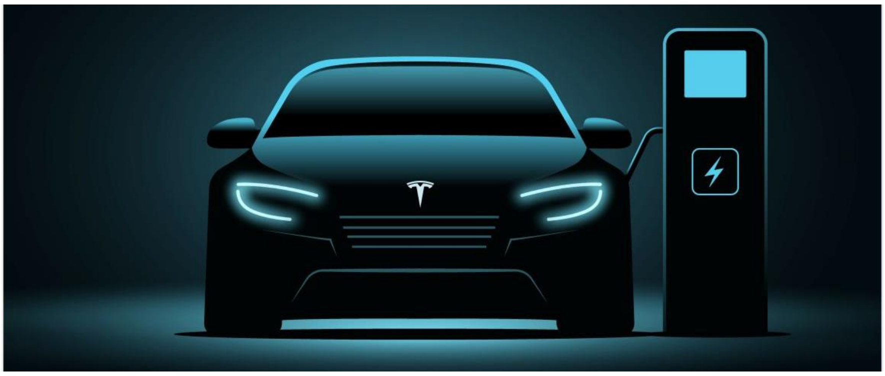
1. Introduction:

Tesla has revolutionized the automotive industry not only through its electric vehicles but also through the integration of advanced hardware and software technologies that power its self-driving capabilities. Tesla's self-driving cars rely on a combination of cutting-edge hardware, such as cameras, sensors, and onboard computing, paired with sophisticated software powered by artificial intelligence and machine learning. These elements work together to create a real-time understanding of the vehicle's surroundings and ensure safe, autonomous driving.

Beyond the core technologies, Tesla is pushing the boundaries of connectivity with the use of the Internet of Things (IoT) and blockchain. IoT enables real-time data exchange between vehicles and their environment, improving decision-making, traffic management, and overall driving efficiency. Blockchain technology plays a crucial role in ensuring the security and integrity of data within autonomous systems, safeguarding vehicle information and driving transactions. Together, these innovations are shaping the future of autonomous vehicles, bringing smarter, more secure, and interconnected driving experiences.



1.1 Background of Tesla

Founded in 2003, Tesla Inc. has revolutionized the automotive industry, becoming a leader in electric vehicles (EVs) and autonomous driving technology. Committed to accelerating the transition to sustainable energy, Tesla's innovative products, starting with the Model S in 2008, set new standards for consumer expectations in the automotive sector.

Initially celebrated for its groundbreaking designs and high-tech features, Tesla faced early production delays but successfully leveraged its reputation to secure critical funding and government support, especially for its autonomous technology. The launch of Tesla Autopilot in 2016 marked a significant milestone, demonstrating the company's dedication to advancing self-driving capabilities.

This commitment is rooted in a series of strategic software upgrades, beginning with a 2014 update that allowed limited steering control, followed by enhancements in 2015 and a major hardware upgrade in 2016. Unlike traditional automakers, Tesla prioritized software and user interface improvements ahead of mass production, giving it a competitive edge in the race for full autonomy. This approach highlights the complexities of the automotive industry, where established giants dominate, and newer entrants struggle. Tesla's innovative trajectory not only emphasizes its technological commitment but also invites scrutiny of the broader corporate dynamics within the sector.

Tesla's Self-driving Cars

Tesla's self-driving car represents a ground-breaking advancement in automotive technology, utilizing sophisticated Artificial Intelligence (AI) and the Internet of Things (IoT) to operate autonomously. These vehicles are designed to navigate roads without human intervention, handling tasks like steering, lane changes, and parking. This automation significantly enhances road safety by reducing the potential for human error, which is a leading cause of traffic accidents.

One of the standout features is the Autopilot driver assistance system, which allows Tesla cars to follow predefined routes and adapt to real-time conditions, such as changing traffic patterns and obstacles. This system continuously learns and improves through over-the-air software updates, ensuring that the vehicle's capabilities evolve over time.

Additionally, Tesla vehicles leverage IoT connectivity to offer a range of remote functions, including climate control adjustments and scheduling maintenance appointments. This integration provides drivers with convenience and enhances the overall user experience.

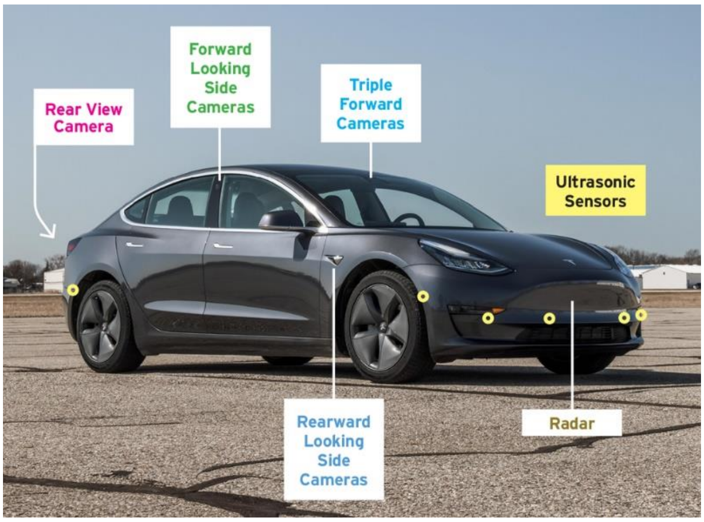
To potential benefits of Tesla's self-driving technology extend beyond individual convenience. By improving traffic flow and reducing accidents, these vehicles could contribute to a safer, more efficient transportation system. Also, upcoming advances in tesla talks about sifting from supervised self-driving to unsupervised self-driving even with more safety than supervised self-driving. As Tesla continues to refine its self-driving features, it aims to redefine the future of mobility in an increasingly interconnected world.

Technology Used

Tesla's self-driving cars uses a combination of advance hardware and sophisticated software to achieve autonomous driving. Here's a breakdown of the key technologies and how they work together:

Hardware Components

Tesla's hardware infrastructure consists of multiple external cameras, ultrasonic sensors, radar, and the Full Self-Driving (FSD) computer, also known as Hardware 3.0. These components work together to monitor the vehicle's surroundings in real-time, providing the input necessary for the software to make driving decisions. The cameras offer a 360-degree view of the environment, while the radar and ultrasonic sensors help detect obstacles and measure distances, even in low visibility.



1. Cameras

Tesla vehicles are equipped with *8 external cameras* that provide a *360-degree view* of the car's surroundings. These cameras have varying ranges and purposes:

- **Forward camera** (long-range): This camera is focused on long-distance vision for detecting objects far ahead, like cars and traffic lights.
- **Wide-angle camera** (forward-facing): Captures a broader field of view, useful for close-up detection in urban environments.
- **Rearview and side cameras:** These monitor the areas around and behind the vehicle, helping in lane changes, parking, and avoiding blind spots.

- ***Purpose:*** The cameras are essential for visual perception, identifying objects, road signs, lane markings, traffic lights, and other vehicles.

2. Ultrasonic Sensors

Tesla cars are equipped with *12 ultrasonic sensors* placed around the vehicle to detect objects in the immediate vicinity. These sensors are especially useful for low-speed maneuvers, like parking and navigating tight spaces.

- **Range:** Ultrasonic sensors have a short range, typically a few meters, but they are very precise in detecting nearby obstacles.
- **Purpose:** These sensors are crucial for proximity detection, helping with parking and close-quarters maneuvering, like avoiding obstacles during slow speeds.

3. Radar

Tesla vehicles use a *forward-facing radar* to detect objects at long ranges, particularly in difficult visibility conditions, like rain, fog, or dust. The radar complements the cameras by seeing through obstacles that cameras might struggle with (like heavy rain or glare from the sun).

- **Purpose:** Radar is key for maintaining safe distances from vehicles ahead, especially in conditions where vision alone might not be reliable. It's used for tasks like adaptive cruise control and collision avoidance.

4. Full Self-Driving (FSD) Computer

Also known as ***Hardware 3.0*** (or Autopilot 3), the FSD computer is Tesla's custom-built processing unit designed specifically to handle the massive amounts of data from the car's cameras, radar, and sensors.

- **Neural Network Processing:** The FSD computer runs neural networks, which are AI models trained to interpret sensor data and make decisions about the car's environment. Tesla's FSD computer is said to be one of the most powerful AI chips in a production car.
- **Purpose:** This computer is the brain of the self-driving system, processing sensor data in real-time and making decisions about how the car should drive, avoid obstacles, or navigate roads.

5. Inertial Measurement Unit (IMU)

The IMU is a sensor that measures the vehicle's movement, including acceleration, tilt, and rotation. This data helps the car maintain stability, navigate curves, and handle challenging driving conditions.

- **Purpose:** IMU data helps the vehicle make precise adjustments, ensuring smooth driving even in uneven terrain or during sudden movements.

6. GPS

Tesla's cars use *Global Positioning System (GPS)* technology to track the vehicle's location and assist with navigation. The GPS works in combination with high-definition maps and real-time traffic data to help plan routes and ensure the vehicle stays on course.

- **Purpose:** GPS helps the vehicle understand its location, plan routes, and follow map data for navigation.

7. Connectivity Hardware

Tesla's vehicles are equipped with *cellular connectivity* and Wi-Fi to support over-the-air (OTA) updates. This allows Tesla to regularly update the car's software, improving features and adding new capabilities without requiring a visit to a service center.

- **Purpose**: Connectivity ensures that the car is always running the latest software version, including any improvements to the self-driving algorithms and safety features.

8. Vehicle Actuators (Steering, Braking, Acceleration)

Tesla's autonomous driving system directly controls the car's *steering, braking*, and *acceleration* through its actuators. These components translate the decisions made by the FSD computer into physical movements.

- **Purpose:** These actuators carry out the vehicle's actions, like making turns, changing lanes, or adjusting speed based on real-time analysis of the environment.

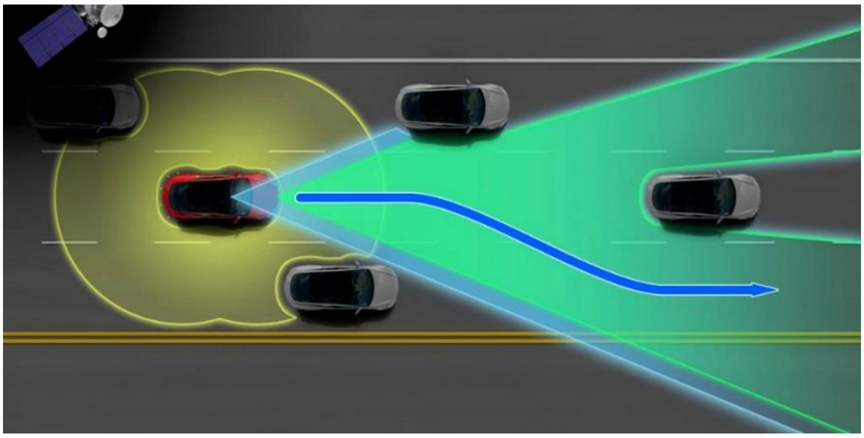
How These Hardware Components Work Together

The cameras, radar, and ultrasonic sensors continuously collect data from the environment, while the FSD computer processes this information using advanced AI algorithms. The car's GPS and mapping systems guide it along the correct route, while the radar and sensors ensure it maintains a safe distance from obstacles and other vehicles. Finally, the actuators (steering, brakes, throttle) execute the driving commands, all while the IMU helps maintain stability.

Together, these components enable Tesla's self-driving cars to navigate roads, avoid hazards, and make driving decisions with minimal human intervention.

Software Technologies

Tesla's software architecture is powered by deep neural networks and machine learning algorithms that process the data from the hardware to make sense of the vehicle's surroundings. This software is capable of interpreting real-time data to recognize objects, predict traffic behavior, and plan safe driving routes. Tesla's AI system is continuously improving, thanks to machine learning that relies on data from the fleet of vehicles on the road. Here's a breakdown of the main software components and how they work:



1. Neural Networks and Artificial Intelligence (AI)

Tesla's self-driving system relies heavily on *deep neural networks (DNNs),* which are AI models trained to recognize patterns in data. These neural networks are designed to interpret inputs from the cameras, radar, and sensors and make sense of the environment around the vehicle.

- **Computer Vision:** Tesla's AI models use *computer vision* techniques to recognize and classify objects such as vehicles, pedestrians, cyclists, lane markings, road signs, and traffic signals. The software "learns" how to drive by being trained on millions of miles of driving data.
- **Purpose:** These neural networks allow the car to understand the complexities of the road, making it possible for the vehicle to navigate urban environments, highways, and more. Tesla continuously trains these networks using data collected from its entire fleet of vehicles, improving the system over time.

2. Path Planning and Decision-Making Algorithms

Tesla's software includes sophisticated *path planning* algorithms that determine the car's course. These algorithms help the vehicle navigate through traffic, handle lane changes, merge onto highways, and avoid obstacles.

- **Predictive Modeling:** The path planning system uses predictive models to anticipate the behavior of other road users (like cars, pedestrians, or cyclists) and adjust its own actions accordingly. For example, the car can predict when a pedestrian might cross the road or when another vehicle may change lanes.

- **Purpose**: Path planning is essential for smooth and safe driving, as it helps the car make real-time decisions like when to change lanes, slow down, or stop.

3. Autopilot and Full Self-Driving (FSD) Software

Tesla's *Autopilot* system is the foundation of its semi-autonomous driving capabilities. Autopilot enables features like lane centering, adaptive cruise control, and lane changes with minimal driver input.

Full Self-Driving (FSD) is a more advanced version of Autopilot, offering a wider range of autonomous features, including:

- **Navigate on Autopilot:** Helps the car drive from one highway on-ramp to an off-ramp, including lane changes and exits.
- **Auto-park:** Automatically parks the car in parallel or perpendicular spaces.
- **Summon:** Allows the car to drive itself to the driver's location from a parking spot.
- **Traffic Light and Stop Sign Control:** Recognizes and responds to traffic signals and stop signs, automatically stopping or proceeding when safe.
- **Purpose:** Autopilot provides hands-free driving for specific tasks, while FSD aims to enable fully autonomous driving under more complex conditions, like city streets and intersections.

4. Sensor Fusion and Data Processing

Sensor Fusion is a key part of Tesla's software that combines data from all of the hardware components (cameras, radar, ultrasonic sensors) to create a complete, real-time map of the vehicle's surroundings. By integrating data from multiple sensors, the software can more accurately detect obstacles and potential hazards.

- **Purpose:** Sensor fusion ensures that the vehicle can navigate safely, even in challenging conditions, by using overlapping sensor data to verify the accuracy of the system's perception.

5. Machine Learning and Over-the-Air (OTA) Updates

- **Machine Learning:** Tesla's AI models continually learn from the data collected by its fleet of vehicles. Every Tesla on the road collects driving data, which is used to refine the AI's decision-making capabilities. This *fleet learning* process improves the self-driving system's performance over time.
- **Over-the-Air (OTA) Updates**: Tesla regularly updates its software via OTA updates, meaning the vehicle's capabilities are constantly improving without needing to visit a

service center. These updates can introduce new features, refine driving behavior, and improve safety.

- **Purpose**: Machine learning and OTA updates are key to Tesla's strategy of continuous improvement. The more data Tesla collects, the better its self-driving system becomes.

6. High-Definition Mapping and GPS Integration

Tesla's cars use *high-definition maps* in combination with GPS to understand the vehicle's location and its relationship to the road network. The mapping system provides information about road layouts, lane configurations, and speed limits, helping the vehicle make informed decisions.

Unlike some other self-driving systems, Tesla relies less on pre-mapped data and more on real-time sensor information, making the system adaptable to changing road conditions.

- **Purpose:** Mapping and GPS help the car stay on course, know the speed limits, and understand the road's layout. It also enables features like *Navigate on Autopilot*, which can automatically follow a pre-planned route on highways.

7. Real-Time Data Processing

The *Full Self-Driving Computer* (Hardware 3.0) processes data from all sensors in real-time. The software is designed to interpret this data quickly and make split-second decisions to ensure the car's safety.

- **Latency Reduction:** Tesla's system is optimized for low-latency, meaning the time between data collection and action (like steering or braking) is minimized. This is crucial for avoiding collisions and making smooth driving decisions.
- **Purpose**: Real-time processing ensures the car can react instantly to its environment, whether it's stopping for a pedestrian or avoiding another vehicle.

8. Safety and Redundancy Systems

Tesla's software is designed with multiple layers of *redundancy* to ensure safety. For example, if one sensor or data stream fails, the system can fall back on other data sources to maintain functionality.

- **Fail-Safe Measures:** The system is also designed to safely disengage or hand control back to the driver if it encounters a situation it cannot handle.
- **Purpose:** Safety and redundancy are key aspects of Tesla's self-driving technology. These systems ensure that the car operates reliably and safely, even in unforeseen circumstances.

9. Human-Machine Interface (HMI)

Tesla's HMI system allows the driver to interact with the self-driving features through the central touchscreen. The driver can enable Autopilot, view real-time visualizations of the vehicle's surroundings, and receive alerts when the system requires human intervention.

- **Driver Monitoring:** Tesla is also working on improving driver monitoring systems to ensure the driver remains attentive when using Autopilot features. Current systems use *steering wheel torque* to detect driver engagement.
- **Purpose**: The HMI ensures a smooth interaction between the driver and the autonomous systems, allowing for easy activation and control of self-driving features.

How the Software Works Together

The neural networks process visual data from the cameras, while sensor fusion combines that with input from the radar, ultrasonic sensors, and GPS. The path planning algorithms use this processed data to make real-time driving decisions, and the FSD computer executes these decisions by controlling the car's steering, acceleration, and braking. Continuous learning from fleet data and regular OTA updates allow Tesla's software to evolve and improve over time.

In essence, Tesla's software stack works in harmony with its hardware to create an autonomous driving experience that gets smarter and more capable with every mile driven.

How They Both Work Together

The synergy between Tesla's *hardware* and *software* is what allows the vehicle to achieve semi-autonomous driving. The cameras and sensors feed data into the FSD computer, which processes the information using AI algorithms. This data fusion enables the vehicle to create a detailed, real-time map of its surroundings. Path planning software then takes this information and generates safe driving routes, while the actuators execute these decisions by controlling the vehicle's steering, acceleration, and braking.

Let's take a more detailed look at how Tesla's *hardware* and *software* components work together to achieve autonomous driving. Understanding this requires examining how the system senses, processes, decides, and acts in real-time.

1. Perception: Sensors and Data Collection

The first step in autonomous driving is collecting data from the environment, which is primarily handled by the hardware components (cameras, radar, ultrasonic sensors, GPS). Here's how they work with the software:

- **Cameras:** Tesla's 8 external cameras capture video footage of the surroundings, providing visual information like road lanes, obstacles, vehicles, pedestrians, and traffic signs.

  The software uses *computer vision* algorithms (powered by neural networks) to analyze the camera feed. These algorithms identify objects, determine their position, speed, and relevance to driving. For instance, they differentiate between a pedestrian crossing the road and a stationary object.

  Example: When a camera detects a pedestrian at a crosswalk, the computer vision system identifies this, recognizes the pedestrian as a high-priority object, and alerts the vehicle's decision-making system.
- **Radar:** The forward-facing radar penetrates through poor weather conditions (rain, fog, etc.) and measures the distance and speed of objects ahead. The software fuses this radar data with the camera data to confirm the presence of vehicles and obstacles. For example, radar might detect a car ahead even if the camera visibility is reduced due to weather conditions.

  Example: Radar data confirms the distance and speed of a car ahead, especially in low-visibility situations, feeding that information into the decision-making system for safe speed management.
- **Ultrasonic Sensors:** These sensors handle proximity detection for short-range objects around the car (up to a few meters), mainly during low-speed maneuvers like parking. The software interprets this data to avoid nearby objects when parking or navigating tight spaces, providing precise measurements for collision avoidance. **Example:** While parking, the ultrasonic sensors detect how close the car is to nearby walls or vehicles, and the software adjusts steering and braking accordingly.
- **GPS and IMU:** GPS and the Inertial Measurement Unit (IMU) track the car's location, speed, and orientation.

  The software integrates GPS data with high-definition maps and real-time sensor data to understand the car's precise location, including its position relative to the road. **Example:** When driving on a highway, the GPS data ensures the car follows the pre-mapped route and assists in path planning for upcoming exits or lane changes.

2. Data Fusion: Integrating Sensor Information

Once the sensors collect data, the next step is *sensor fusion*. This process integrates inputs from the cameras, radar, ultrasonic sensors, GPS, and IMU to build a comprehensive view of the car's environment.

- **Purpose:** No single sensor provides perfect information. For example, cameras can be affected by lighting, radar can struggle with certain small objects, and ultrasonic sensors have limited range. By fusing data from all sensors, the system compensates for each sensor's limitations and creates a more accurate model of the surroundings.
- **Software Role:** Tesla's software performs sensor fusion in real-time, using advanced algorithms to combine inputs into a cohesive "world model" of the vehicle's surroundings. This model informs the car's understanding of its environment, including obstacles, road conditions, and traffic behavior.

  Example: When merging onto a highway, the cameras detect the lanes, radar monitors the speed of nearby vehicles, and the ultrasonic sensors check for obstacles in the blind spots. The software combines all this data to decide when it's safe to merge.

3. Perception: Neural Networks for Object Recognition

After sensor fusion, Tesla's *neural networks* take over to interpret the processed data. These AI models are trained to recognize objects and categorize them based on relevance to driving.

- **Computer Vision:** Tesla's software uses deep learning models to classify objects (cars, trucks, pedestrians, cyclists, etc.) and understand their behavior. These models are trained on vast amounts of data from Tesla's fleet, allowing the system to improve its accuracy over time.

Example: A neural network recognizes a cyclist ahead and predicts their movement. If the cyclist is about to enter the car's path, the system will adjust its driving to avoid a collision.

- **Predictive Behavior Modeling:** Tesla's AI also predicts the future behavior of dynamic objects. For example, it can estimate whether a pedestrian will step onto the road or if a vehicle is likely to change lanes.

  Example: When the software detects a pedestrian near the edge of a crosswalk, it may predict that the pedestrian will cross, triggering the car to slow down in anticipation.

4. Path Planning and Decision-Making

Once the perception layer has built a detailed understanding of the environment, the next task is *path planning*. The software needs to decide how the car should react to its environment and where it should go.

- **Path Planning Algorithms:** Tesla's path planning software evaluates various possible trajectories the car can take and selects the safest, most efficient one. It takes into account:
  - Road conditions (e.g., lane markings, traffic signals)
  - Movement of other vehicles and pedestrians
  - Traffic rules (e.g., speed limits, stop signs)
  - Dynamic obstacles (e.g., other cars, pedestrians)

Example: If the vehicle needs to change lanes on a highway, the software checks whether the adjacent lane is clear, estimates the speed of vehicles in that lane, and decides whether to change lanes now or wait for a safer opportunity.

- **Predictive Modeling:** Tesla's system doesn't just react to the current situation; it also predicts future states. For example, the car may anticipate that a vehicle ahead will slow down based on its trajectory and adjust its speed in advance. **Example:** If the software predicts that a car ahead is going to slow down due to heavy traffic, it may proactively reduce speed to avoid abrupt braking.

5. Action: Controlling the Vehicle's Movements

After the path planning system makes decisions, the software sends commands to the *actuators* (steering, braking, and throttle) that control the vehicle.

- **Steering Control:** Based on the planned path, the software adjusts the steering to keep the car in its lane, perform turns, or change lanes. **Example:** On a highway, the software gently adjusts the steering to keep the car centered in its lane, taking into account any curves in the road.
- **Acceleration and Braking Control**: The software manages speed based on road conditions and the behavior of nearby vehicles. It applies acceleration or braking to ensure smooth driving.

  Example: If a vehicle in front slows down, the software will smoothly reduce the car's speed by applying the brakes. If the road ahead is clear, it will gradually accelerate back to the set speed.

6. Real-Time Feedback Loop

One of the most important aspects of Tesla's system is its *real-time feedback loop.* The car continuously monitors its environment and adjusts its behavior accordingly.

- **Constant Monitoring:** The sensors collect new data every fraction of a second. The software constantly updates its world model and recalculates the best driving actions based on any changes in the environment.
- **Real-Time Adjustments:** If the software detects an unexpected obstacle or a change in traffic conditions, it will instantly update its path and take new actions to ensure safety.

Example: If a car ahead suddenly changes lanes, Tesla's software will quickly reassess the new open lane, adjust its speed if necessary, and steer to maintain lane position.

7. Machine Learning and Over-the-Air (OTA) Updates

A crucial part of how Tesla's software evolves is through *machine learning* and continuous improvement.

- **Fleet Learning:** Tesla cars collect massive amounts of data from their sensors as they drive. This data is sent back to Tesla's servers, where the AI models are further refined and retrained.
- **OTA Updates:** Tesla regularly pushes *over-the-air (OTA) updates* to improve the self-driving software, fix bugs, and add new features. These updates allow the entire fleet to benefit from improvements learned through collective driving data.

  Example: If Tesla improves the way its cars detect cyclists, this update will be sent to all vehicles, enhancing the safety and accuracy of its entire fleet.

Conclusion: The Hardware-Software Symbiosis

In summary, Tesla's self-driving system is a sophisticated integration of hardware (sensors, cameras, actuators) and software (neural networks, path planning, sensor fusion) that constantly interact with each other:

- Sensors (Hardware): Capture detailed data about the environment.
- Software (AI and Sensor Fusion): Processes and interprets the data, recognizing objects and road conditions.
- Path Planning (Algorithms): Determines the best course of action.
- Actuation (Hardware): Executes the decisions, adjusting steering, braking, and acceleration.
- Feedback Loop: Continuously monitors the environment and updates decisions in real-time.

This continuous flow of data between hardware and software enables Tesla's self-driving cars to navigate complex driving environments with minimal human input, while also improving over time through fleet learning and OTA updates.

How IoT plays the role

The first self-driving car was a Mercedes van built by Dickmanns in 1986. It was able to reach a top speed of 96 km/h. In 2014, Elon Musk launched a self-driving car or the car was completely made of IoT and Blockchain. One of the biggest names in the automobile industry is also leveraging IoT to make its connected vehicles smarter and smoother to use. Here is a brief case of IoT uses:

Self-driving car: IoT allows Tesla's cars to connect to a cloud system and share information about the road and the car's movement. This data is used to analyse navigation, traffic, and roads, which helps the car drive itself.

- **Vehicle production lines**: Tesla uses IoT to monitor and optimize processes on their vehicle production lines.
- **Remote diagnostics:** Tesla uses IoT to provide remote diagnostics for their electric vehicles.
- **Predictive maintenance:** Tesla uses IoT to collect data from sensors in the vehicle to predict when components might fail or need maintenance.
- **Over-the-air software updates:** Tesla uses IoT to provide over-the-air software updates to their vehicles. For example, Tesla used this technology to:
    - Notify owners of a safety issue with a charger plug.
    - Adjust the cars' suspension settings.
    - Improve Bluetooth capabilities.
    - Improve the way the car handles while driving.

IoT in the automotive industry refers to embedding sensors, actuators, and other IoT technologies into automobiles. The goal is to create solutions that make vehicles smarter, efficient, and more intelligent. There are many IoT-based solutions that are shaping the new automotive age, including:

- Predictive maintenance

- Advanced Driver Assistance Systems (ADAS)
- 3G/4G/5G powered Wi-Fi functionality
- Car2Car connectivity
- In-vehicle infotainment system

With IoT, connected cars are making life easier for both drivers and carmakers, in terms of electronic upgrades. An IoT embedded car enables you to control and monitor your vehicle's stats. You can do this with just a single tap on the app.

What Blockchain has done

One major concern in the IoT landscape is security. As vulnerabilities pose significant risks, making it imperative to establish robust mechanisms for safeguarding sensitive data. The interconnected nature of vehicles and their reliance on data exchange create potential entry points for cyber-attacks, privacy breaches, and data manipulation. Here, block chain technology comes into play as a promising solution to these challenges.

Research indicates that integrating block chain can significantly enhance the security of data exchanges between connected devices and IoT platforms. A Frost and Sullivan report suggests that by 2025, 10% to 15% of connected vehicle transactions may utilize block chain. This projection underscores the growing recognition of block chain's capabilities in addressing security concerns in the automotive industry

In block chain, almost any document or asset can be expressed as a code and referenced by a ledger entry, which fundamentally means that blockchain technology has vast applicability. Some of the fundamentals on which blockchain works are as follows:

- **Immutability** - It is almost impossible to make changes to the blockchain without detection, thereby increasing confidence in the information it carries and reducing chances of fraud. Once the data is created and stored, it cannot be edited or deleted, i.e., a ledger cannot be changed or altered.

- **Automated Backups and Transparency** -The automated backup feature of blockchain further enhances its security profile. Data is continuously updated and synchronized across multiple nodes, providing resilience against data loss and corruption. This decentralized backup system ensures that critical information is always available, even in the event of a cyber-attack or system failure.

Additionally, block chain promotes transparency within the automotive ecosystem. Each transaction or data entry is recorded in an immutable ledger, allowing stakeholders—manufacturers, suppliers, dealerships, and consumers—to trace the history and provenance of parts, vehicles, and transactions. This level of transparency fosters trusts among participants in the supply chain, reducing the likelihood of fraud and misrepresentation.

- **Transparency** – Transactions are visible to all participants, with identical copies maintained on multiple computer systems, which increasing the ability to audit and trust the information. Additionally, it can track every system detail.
- **Security** – Blockchain's inherent characteristics provide a strong framework for securing data in the automotive sector. Its decentralized structure means that data is not stored in a single location, reducing the risk of data breaches. Instead, information is distributed across a network of nodes, each of which maintains a copy of the entire blockchain. This redundancy ensures that even if one node is compromised, the overall integrity of the data remains intact. It uses encryption and decryption methodologies. Data once recorded with a timestamp cannot be tampered or changed. Additionally, once the data is stored, it cannot be overwritten or manipulated. As multiple participants share a blockchain, it has no single point of failure and is resilient in the face of outages or attacks.
- **Efficiency** – As there is no third-party involved, transactions happen directly, which results in saving of time & money.
- **Near-Real time** – The settlement of recorded transactions happens almost instantaneously, removing friction and reducing risks.

Blockchain technology is crucial for securing data in autonomous vehicles. Tesla's self-driving cars use blockchain to store and share data securely, preventing tampering and ensuring transparency. By decentralizing storage and creating immutable records, blockchain build trust in autonomous system by safeguarding vehicle performance, accident, and decision-making data.

Conclusion:

In conclusion, Tesla has revolutionized the automotive industry with its groundbreaking advancements in autonomous driving technology, blending sophisticated hardware, cutting-edge software, and emerging technologies like IoT and blockchain. Tesla's vehicles, equipped with an array of sensors, cameras, and Full Self-Driving (FSD) computers, are designed to autonomously navigate roads with minimal human input, thanks to AI-powered neural networks that process vast amounts of real-time data. These technologies enable Tesla cars to not only perceive and interpret their surroundings but also make intelligent decisions that enhance road safety, reduce traffic accidents, and improve driving efficiency.

The integration of the Internet of Things (IoT) allows Tesla's vehicles to communicate with their environments, sharing critical information that supports real-time traffic management and predictive maintenance. Blockchain technology further strengthens this ecosystem by providing enhanced data security and transparency, ensuring the integrity of vehicle data, transactions, and system operations in a decentralized manner. These advancements address key concerns related to cybersecurity in connected vehicles and lay the foundation for more reliable and secure autonomous systems.

Moreover, Tesla's strategy of continuous improvement through over-the-air (OTA) software updates and machine learning ensures that its self-driving technology evolves and improves over time, benefiting from collective data gathered from its fleet of vehicles. As the cars on the road generate more data, Tesla refines its systems, making each update more intelligent, safe, and responsive.

Tesla's innovations extend beyond just individual vehicle performance; they promise to reshape the entire landscape of transportation. By contributing to improved traffic flow, reducing human error, and fostering a more interconnected driving experience, Tesla's autonomous vehicles are set to play a pivotal role in transforming modern mobility. As the company continues to push the boundaries of what's possible in electric and autonomous vehicles, its vision is creating a future where sustainable, smart, and fully autonomous transportation becomes a global reality.

Tesla's approach—fusing state-of-the-art hardware, AI-driven software, IoT connectivity, and blockchain security—positions it as a leader in shaping the future of autonomous driving. This ambitious vision signals a profound shift in how we move, paving the way for safer roads, cleaner energy, and a seamlessly connected transportation infrastructure that will redefine mobility in the years to come.

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THE ROLE OF BLOCKCHAIN TECHNOLOGY IN ADVANCING SCIENTIFIC RESEARCH

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1. Introduction to Blockchain Technology

The decentralized and distributed ledger system known as the blockchain provides the foundation for the operation of smart contracts and cryptocurrencies. It facilitates secure transaction procedures based on cryptography, transparent electronic voting systems, tracking of physical inventories, and a single method of carrying out asset exchanges. Three essential design elements are integrated into and incorporated by blockchain: a proof-of-work layer that cryptographically protects data stored in blocks, a data structure that functions as a framework, and a security feature that ensures the integrity of data stored in blocks is impervious to tampering. This guarantees that the transactions included inside a block are unchangeable, hence opening the possibility of immutable tracing capabilities that can demonstrate the ownership and provenance of transactions. Since a safe mix of cryptographic algorithms and access restrictions provides data privacy and verifiability along with integrity, traceability, and decentralization, blockchain technology has shown promise in recent years to change trust-based businesses. Gaining the confidence of important stakeholders might lead to more acceptability, which could speed up the implementation of this new technology. Blockchain has been the essential building element for improving virtual currency transactions over time. Its use extends beyond cryptocurrencies and transforms how we create and plan safe, unchangeable procedures for shared trust. Currently, many blockchain applications exist as publicly acknowledged open blockchains that are accessible to all stakeholders. As a result, the contemporary blockchain movement is mostly concerned with creating blockchains that encourage natural cooperation between stakeholders in closed organizations. These are the permissioned/consortium blockchains, which are based on the same fundamental ideas as permissionless blockchains: distributed ledgers, anonymity, scarcity, written information records, data security, and immutability of records. In light of this, we believe that these qualities will be essential for furthering scientific inquiry and executing the verification of fundamental scientific concepts, such as the reproducibility of research findings.

1.1. Definition and Key Features

The creators of blockchain technology are an anonymous individual or group of individuals going by the handle Satoshi Nakamoto. The core idea behind blockchain is based on a narrowly defined but precise definition that includes four main elements: (a) an expanding list of entries called blocks; (b) cryptographically linked and secured; (c) stored on a decentralized network of participants, meaning that once recorded, it cannot be altered; and (d) viewed as an open distributed ledger. This highlights the fact that a blockchain is an extremely safe, trust-extending, and tamper-evident technology.

With no single point of control, DLT is progressed thanks to the databases that are unquestionably centralized. For example, when a database containing all the collective knowledge is needed, permissionless DLT allows for open access and broadcast communication. Limited access, which requires all parties accessing it to send and authenticate their access before joining the network, is the main characteristic of the permissioned DLT. One more crucial feature of a blockchain is the extremely unlikely removal or alteration of data included in a block once the block is included in the chain. A blockchain's remaining blocks must also be changed to update a particular piece of data.

Every block that is created is validated by most networks, and subsequent blocks rely on the accuracy of the previous ones. As a result, everyone in the next block may calculate any change in any value. It maintains a consensus for the creation, confirmation, or recording of a legitimate transaction through a variety of consensus techniques. These concerns with security and trust might be resolved by the salient characteristics of blockchain technology, such as decentralization, immutability, and consensus procedures. This is why blockchain's intrinsic qualities and capabilities are gaining attention around the world as a game-changing technology.

1.2. Brief History and Evolution

Every technical advancement that aims to address current problems and improve society has a backstory and a purpose for existing. There is a strong inclination to view blockchain as operational from the day of creation. This is the situation. Therefore, it is important to keep in mind that the idea of a blockchain offers a platform for transactions and data storage that can validate everything in an uncorruptible and transparent manner. It accomplishes this by securely managing a dispersed user network. Those closest to us wanted to handle digital currency on a public network and wean ourselves off middlemen, but at first the emphasis was on supporting currencies.

The first blockchain theory was presented in 2008. The first software that enabled the first blockchain in the form of a cryptocurrency was made available in 2009. By 2013, the original system had divided into two, making the blockchain stronger. Though the general features were lighter, the public and the development of alternative big money remained the primary focus. This initial Department of Currency, economy, and gold was supported by the community. The second solution attempted to combine live decomposition with more to enhance the blockchain's nature.

The number of blockchain technologies has already risen to the top of audience rankings in 2014. Many already-running software applications had been modified to store development logs in distributed databases. Though the format's rapid market expansion came at the price of the growth of digital assets, other systems were created to take advantage of other prospects. The concept of scalability emerged in 2015 when alternative configurations were used.

Due to growing demand, some others tried to reorganize the backlog of transactions. The community has previously decided to change it and implement a procedure known as a "hard fork" to attain a more stable capability. The off chain tracking of micropayments has become less widespread, and the micropayment network and channels have quickly become a mode of operation. Blockchain is used in more areas than only banking, including supply chains and logistics, recreation, sports, sewage, help, and science. A growing number of theories validate the properties of the blockchain as it gets more complex. Maybe we should consider the generations of blockchains as well. A fresh generation of assets was manufactured and repackaged, while the first generation approved the cryptocurrency over the blockchain.

2. Challenges in the Current Scientific Research Landscape

The scientific community is facing a reproducibility crisis, where many research findings cannot be consistently replicated, raising doubts about the authenticity of scientific knowledge. This issue stems from biases, flawed methodologies, and selective reporting, leading to unreliable results. Journals and funding bodies often favor results that align with accepted theories, reducing objectivity. Additionally, the vast amount of data generated today poses challenges in data management and security, with a significant rise in data breaches, especially in sectors like healthcare. Ensuring data integrity, confidentiality, and security has become critical as sensitive information is increasingly stored electronically, calling for innovative solutions to improve trust and reliability in scientific research.

2.1. Reproducibility Crisis

The reproducibility crisis challenges the credibility of the scientific process, as many studies fail to replicate prior results. While this does not always imply the original findings were wrong, it raises concerns about research reliability. Factors such as methodological flaws and economic pressures contribute to this crisis, affecting trust in scientific progress and potentially reducing research funding. Blockchain technology has the potential to enhance transparency and accountability in research by addressing these issues.

2.2. Data Integrity and Security Concerns

Data integrity, particularly in preclinical research, is crucial, as compromised data can lead to erroneous conclusions, especially in drug safety testing. The rise in cyberattacks has further heightened concerns about data security in research. Traditional methods of safeguarding research data are being challenged by these threats, but technologies like blockchain could offer solutions for improving data integrity and collaboration within the scientific community.

3. Applications of Blockchain in Scientific Research

Blockchain is emerging as a groundbreaking technology with the potential to transform scientific research. One of its key strengths lies in its decentralized structure, which allows researchers to share and collaborate on data in a transparent and verifiable manner. By utilizing cryptographic keys and a peer-to-peer network, blockchain ensures the integrity of datasets, preventing unauthorized tampering. Additionally, blockchain can streamline workflows in research collaborations, offering traceability of intellectual property (IP) rights, a crucial asset for academics.

Initially designed for cryptocurrency like Bitcoin, blockchain's role has expanded to include securing digital property. In scientific research, it can ensure the proper sequence of data and prevent retroactive modifications, creating a robust provenance management system. This system safeguards IP ownership and usage rights, ensuring patents are awarded fairly and infringement claims are valid. A case study involving contract research demonstrated blockchain’s ability to establish data ownership and protect it.

Beyond IP management, blockchain can revolutionize research networks by creating trusted, transparent collaboration across institutions. It provides a competitive edge by securely managing IP ownership and enhancing collaboration. Its applications could extend to academic publishing, citations, grant funding, and research contracts, offering new models of transparency and commercialization in science. Ultimately, blockchain's ability to manage both the products and processes of science aligns with the values of transparency, trust, and collective knowledge. With proper ethical frameworks, blockchain can democratize science, benefiting a global audience and ensuring equitable access to scientific knowledge and innovation.

3.1. Data Sharing and Collaboration

The availability of valuable data is often restricted by data access policies, lack of trust from data owners, and the absence of standardized formats for data exchange. While the potential of open data is widely acknowledged, the concept has garnered support across various disciplines, governmental bodies, and institutions. A blockchain-based system offers promising solutions to these challenges by enabling the creation of secure and transparent data-sharing networks. This is particularly beneficial for the secondary use of health and environmental data.

As research continuously produces vast volumes of data, blockchain can help streamline the process of managing and sharing this information securely. The time is ripe for a community-driven initiative to align and invest in ethical, transparent platforms for research data sharing. Blockchain is increasingly seen as a disruptive technology for managing scientific research data, although many current initiatives are still in early stages, and detailed implementation is under discussion.

Blockchain's potential to share data securely and preserve privacy is promising, but challenges remain in designing incentive mechanisms and establishing standards to ensure secure data exchange. By implementing blockchain, data owners can be encouraged to share their data, with the assurance that the authenticity of the data can be easily verified. Successful deployment of such systems could enhance cooperation between data owners and users, fostering a culture of collaboration and trust in research data exchange.

3.2. Intellectual Property Protection

In all areas of scientific collaboration, particularly in academic-industry partnerships, the protection of intellectual property rights (IPR) has become increasingly crucial. Researchers often hesitate to share their findings and ideas with potential collaborators or the public before securing patents, fearing unauthorized use. Unintended disclosure of research can result in the loss of exploitability, making it difficult to protect or profit from new innovations.

To address these challenges, blockchain technology offers a secure way to record and timestamp research outputs, establishing proof of ownership and priority for international patent filings. This immutability increases the likelihood of research being recognized by patent examiners globally, improving the chances of securing patents. Today, blockchain is used across various domains. For instance: In the dental research industry, blockchain networks allow dentists and labs to securely exchange findings and protect their intellectual property.

Artists and creators can register their works on blockchain, proving authenticity and defending against unauthorized reproductions. An app exists that enables the creation and distribution of official collector's editions of digital assets with verifiable scarcity, authenticity, and provenance on blockchain.

In scientific publishing, companies use blockchain to timestamp and secure analysis data submitted with manuscripts, ensuring data authenticity. By enhancing IP protection in both public and industry-funded research, blockchain technology fosters stronger collaborations in science. With blockchain's privacy-preserving and trust-enhancing features, collaborations between computational and biological researchers and patients in decentralized networks will likely become more efficient, resulting in increased data sharing and better use of research outputs. Overall, blockchain boosts the trustworthiness of research, encouraging the adoption of new methodologies in the scientific community.

4. Case Studies of Blockchain Implementation in Science

Case studies of blockchain technology in scientific research provide a clear illustration of how the theoretical background outlined in Section 3 is being put into practice. This section will demonstrate two different applications of blockchain technology in the realm of scientific research. First, it will discuss academic publishing platforms that have been built using the principles of blockchain to create a transparent review process that will make it more difficult for those involved in misconduct to remain hidden. Second, it will investigate blockchain-based research data repositories that seek to enhance data provenance and management and provide a clear understanding of how researchers and institutions intend to engage with and make use of these platforms. It will draw out the significance of these case studies in challenging the traditional model of research dissemination that sees peer-reviewed published output as the only valid form of scholarly output.

4.1. Academic Publishing Platforms

The current peer review process, which assesses scholarly work for quality and originality, is often complicated by secrecy and reliance on trust. Traditional publication forums frequently restrict access to content, requiring institutions to pay high subscription fees for research papers. Even more concerning is that peer review is conducted confidentially, relying heavily on the honesty and expertise of reviewers. This can lead to flawed research being published, causing researchers to waste time and resources trying to reproduce faulty experiments, with potential damage to their reputations. A proposed solution to these issues is a blockchain-based smart contract system, which would increase accountability by recording and documenting every stage of the peer review process on an immutable ledger. This would create transparency while protecting the integrity of the review process. By maintaining an auditable record of actions, blockchain could ensure that reviewers are held responsible for their assessments. To further reform the system, blockchain could also eliminate traditional editors from assigning reviewers, which may require a complete overhaul of the publishing industry, including the removal of double-blind review or the creation of alternative platforms without conflicts of interest. Blockchain platforms could significantly reduce publication costs by allowing articles to be simultaneously submitted to multiple journals, providing an affordable and efficient alternative to the current model. In fact, blockchains have already been applied in the academic publishing industry with various degrees of success. Their primary goals include streamlining the review process, offering alternative models for cost recovery, securing authorship rights, and ensuring greater accessibility to research. Blockchain technology offers the potential for a more transparent, accountable, and accessible future in scientific publishing, addressing many of the limitations of the traditional peer review process.

5. Potential Future Developments and Trends

Smart Contracts and Efficiency: Smart contracts could potentially automate the processes through which research agreements are created, shared, and remotely signed online. These files could then be directly used for incentivizing the parties as encoded in the contracts. Similarly, academic or commercial end users of research outcomes could help fund these projects on a smaller level using micropayments and obtain shares or results from the research. This could reduce much of the administrative burden of funding managers and research administrators. DAOs to Replace Research Institutions: In the near future, innovations such as these could coalesce into sophisticated, essentially 'decentralized autonomous organizations' (DAOs) that control scientific funds using blockchains. Such entities might have widespread beneficial implications throughout scientific research. They could facilitate investigative projects with collaborators that span many institutions or even transnational geographical locations. In other words, these DAOs could enable the scaling and acceleration of global collaboration. Their advantageous implications are also likely to extend beyond large-scale research on scientific infrastructures or applications requiring extensive data resources and supercomputing time to basic, applied, and translational research. More efficient use would also mean reducing the economic and social cost of the present arm's length funding models. Challenges: Ethical, legal, social, and technological challenges that should form topics for further research and debate—for example, reduced information symmetry in collaboration networks, the disintermediation of large funding agencies, the rise of a new scientific elite, or funding distribution according to the whims of cryptocurrencies and blockchain platforms. Even though the technology is already with us, its applications and implications are just beginning to become visible. This means the entire research landscape is changing fundamentally and will likely lead to a renewed arms race among researchers and research institutions. [3][4]

6. Conclusion and Summary of Key Findings

In this publication, we explored the transformative potential of blockchain technology in various aspects of scientific research. Blockchain can be applied in data storage platforms, data-sharing infrastructures, and the management of intellectual property, research funding, and collaborations. The key benefits of integrating blockchain into research are centred on trust, security, and privacy. Blockchain could address critical challenges like data integrity, reproducibility of scientific findings, interdisciplinary collaboration, and secure research funding.

By promoting the development of decentralized financial infrastructures, blockchain technology can support research funding, enabling multi-stakeholder management systems that improve transparency and offer exit strategies for national and international public funds. Blockchain and peer-to-peer technologies foster trust within research collaborations by providing clear records of data ownership, ensuring ethical compliance, and minimizing risks of data manipulation or misuse.

Despite these benefits, the successful adoption of blockchain technology in scientific research will depend on establishing robust legal and ethical frameworks. The interdisciplinary nature of blockchain's integration into research indicates a trend towards increased collaboration between the tech and scientific communities. Continued progress will require projects to embrace open data and open-source software, ensuring transparency and encouraging inclusive dialogue between developers and researchers. While theoretical discussions and visualizations of blockchain's applications are already emerging, empirical analysis is still necessary to refine these systems and ensure their practical implementation in the context of scientific research. This publication underscores the potential of blockchain to revolutionize science but emphasizes that further exploration is needed to unlock its full capabilities.

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THE CONVERGENCE OF COMPUTER SCIENCE AND GREEN TECHNOLOGY FOR A SUSTAINABLE ENVIRONMENT

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Abstract:

In recent times the term sustainability has Gardner attention to co-exists the world over a long period with protection. Apart from that it ensures each individual should enjoy health, justice and prosperity. To address environment issues every industry must implement sustainable practices with the advent of technology like Green computing. Computer Science has placed the major role to encourage sustainability and stimulate the progress by utilising energy efficiently. From mobile phones software to machine learning training models in data centres, consumes electricity and release the heat energy. To slash down the carbon footprint, computer scientist may support by creating algorithms and methods to optimise the energy usage. To emphasize this environment, Green Technology will support for sustainability. The environmental friendly hardware, software and resources usage is referred as Green computing. This paper describe the role of different domains of computer science which are involved in minimizing the electronic waste, energy consumption, release of heat and effective usage of a power etc.

Keywords: Green Computing, Renewal Energy, Smart Grids, Data Analytics, Sustainability.

I. Introduction:

In digital world, our routine and professional activities have been changing by the advent of computers. By introducing an advanced algorithm and models, Computer Science becomes an instrument in shaping the digitalised modern world. In the scenario, it is more essential for us to think about the environmental impact of technology in industries. To live in a sustainable environment the efficient use of energy is the major area to be concentrated. It can be achieved by utilising domain of Computer Science like Artificial Intelligence, Internet of Things, Data Analytics and Green Technology.

II) The role of AI:

AI emerged as cutting edge in shaping solutions for environmental sustainability in many ways.

A) **Energy Management:**

AI can help to optimise energy consumption in buildings factories transportation system agriculture. By analysing real-time data AI identify and recommend energy saving measures by reducing energy sectors to maintain emission that can be reduced and energy being managed.

B) Smart Grid:

Smart Grid is an electricity network that uses advanced digital technology. In smart grid, AI based algorithms creates dynamic and self adjusting power grids[1]. These grades manage energy intelligently balance the sources of renewable energy according to the demand. The objective is to provide precise control over action with security measurements and high accuracy.

III) The role of Green Technology:

The computer science and green technology share a symbol symbiotic relationship in driving sustainable development in various providers data centres which constitutes full of high and service designed to automate and create a service to companies or individuals. Some of the sustainable software development principles or listed below:

A) The Power Usage Effectiveness (PUE)

This metric is widely used by the data centre to measure energy efficiently efficiency it is determined by dividing the total amount of power entering data centre by the power used to run the required it equipments when effectiveness 1.0 the energy it indicates higher proportion of power is used and smaller amount is used for cooling and other overheads during the operations.

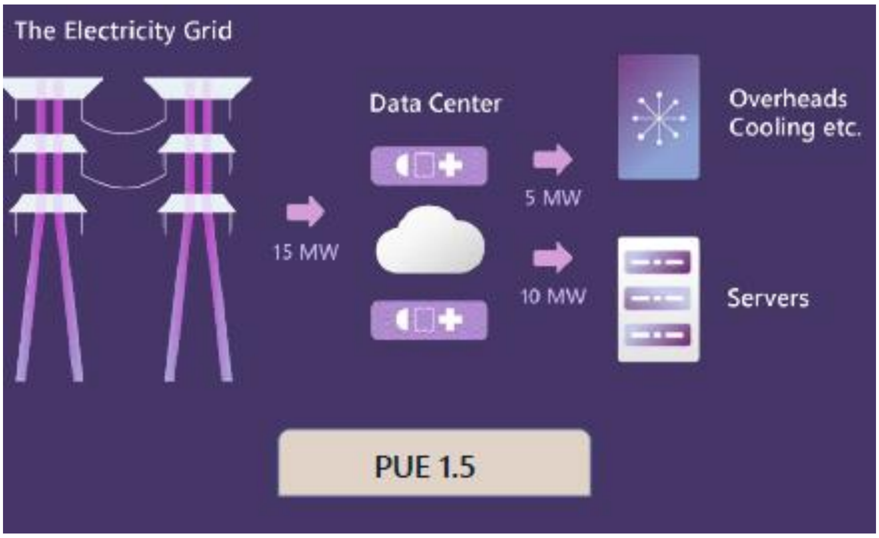

Figure 1: Power Usage Effectiveness Management

B) Energy Proportionality

It measures relationship between Power consumed by a computer and rate at which utilisation is made. It is expressed in percentage the high percentage for fully utilised computer and ideal computer shows a lower percentage of energy proposed consumption. The relationship between our consumption and utilisation is not linear proportionate.

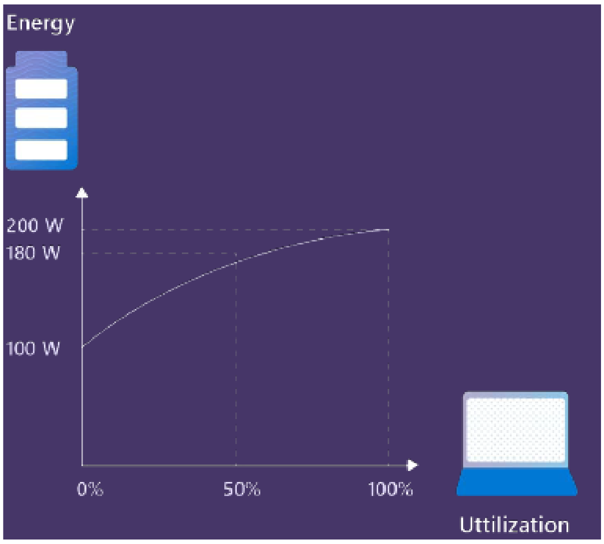

Figure 2: Energy Proportionality graph

So, computer more efficiently by converting electricity to your computing operations practically to improve hardware efficiency that is recommended to run the whole workload on few services as much as possible with highest utilization of service and maximization energy efficiently.

C) The Static Power Draw

The static power draw of a computer is how much electricity is drawn when the system is idle. If the device is idle, it will eventually trigger the hibernation mode and put the screen and the disc to sleep. Sometimes it may change the CPU frequency. The power saving mode saves electricity such as slow or restart when device wake up. Servers are configured for aggressive functionality with no power saving mode. The rapidly changing demands which may lead to others servers in idle mode, during no demand periods. An idle server has carbon cost from both embedded carbon as well as its inefficient utilisation.

IV) **Advantages of Computer Science in Green Technology**

The Green computing aims to reduce the impact over environment and it encourages the wide spread use of more sustainable technologies.

A) **Lowering Energy Cost**

By lowering the electricity can lower the cost of energy for business. More the energy efficient devices with the optimal resource allocation will lead to energy in cost effective way.

B) **Increase Efficiency**

The efficiency of resources will increase with optimized energy consumption algorithm, which reduces the wastage to minimal.

C) **Increasing Innovation**

Green computing practices refer to development new products services processes which lead to sustainable and profitable business.

D) **Data Driven Decision Making**:

Computer science enables the collection and analysis of real time data empowering the organization to make informed decisions for sustainability.

V) Future of Green Technology in Computer Science

Green computing is a promising area of technology which is expected to grow rapidly and more widely adopted. It can help to achieve environmental goals like reducing greenhouse gas emission and combating climate change.

A) **Circular IT Economy**

Green technology indulge algorithm to recycle the components or reuse the model, which more easily adopted. In future it will lay a path for circular it economy.

B) **Green Data Centre**

In future, workstation equipped with advanced digital infrastructure. So computer scientist will explore methods to design and operate the energy efficient data centres, with reduced emission of heat energy and self regulating system.

Conclusion:

Computer science has a profound impact on sustainable development and advancement of green technology with reduced carbon emission and more energy efficient production system. It will drive towards the sustainable solutions across various sectors the collaboration between computer science and green technology clenches the immense potential for achieving a greener and more sustainability in future

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STUDIES ON THE THERMAL DECOMPOSITION OF TOBACCO FROM DIFFERENT SOURCES AND THEIR OXIDATION USING MODIFIED HUMMER'S METHOD

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Abstract:

Tobacco has been used commonly as chewing tobacco, snuff and cigarettes in large quantities. Thermal decomposition and their characterization of the above types of tobacco might be of significant interest. In this work we have investigated the products formed on thermal decomposition of chewing tobacco and tobacco collected from cigarette. The resulting black colour products were characterized using EDXA to obtain the composition, infrared spectrometry to identify different types of functional groups, powder X-ray diffractometer to detect the compounds and phases, UV-visible spectra to obtain information about the transitions and band gap. Scanning electron microscopic study provides information about the morphology of the samples. Thermal decomposed products obtained from chewing tobacco/tobacco from cigarette shows the formation of amorphous carbon (major component), calcium carbonate (minor phase) and potassium chloride (minor phase). The thermally decomposed products obtained from chewing tobacco/tobacco from cigarette were subjected to oxidation using Hummer's method to prepare graphite oxide (from amorphous carbon). During the process the minor components-calcium carbonate gets converted to anhydrous calcium sulphate and amorphous carbon to amorphous form of graphite oxide. The phases formed during the thermal decomposition and oxidation processes have been confirmed by the above characterization techniques. The UV-visible diffused reflectance spectra show the band gap around 1 eV for the oxidation products and exhibit has irregular platelet/sheet like morphology.

Keywords: Chewing Tobacco, Tobacco from Cigarette, Thermal Decomposition, Modified Hummers Method, Heterogeneity.

1. Introduction:

Cigarettes, cigars, pipes, bidis, kreteks, dhokas and hookahs all employ tobacco, as do chewed tobacco, snuff, dip, and snus products. More than 33% of adult population use tobacco in one way or the other [1]. According to WHO reports, almost 13 lakh people die from smoking (cigarettes) each year, and more individuals have been impacted by passive smoking of tobacco [2,3]. The three most popular usages are in cigarettes, snuff, and chewing tobacco. Nitocine, which is included in all of the aforementioned tobacco products, is easily absorbed into the blood and epinephrine is released by the adrenal glands [4]. The central nervous system is stimulated by epinephrine, which also raises blood pressure and heart rate [5]. Smoking tobacco causes emphysema, bronchitis and lung cancer. While chewing tobacco has the lowest doses of nicotine and can cause throat cancer, it also raises the risk of heart attack, cancer, cataract, and type 2 diabetes [6,7].

The complex blend of natural ingredients and additives found in tobacco products includes numerous volatile and semi-volatile organic substances at trace levels [8]. The extract contains nicotine, ethyl citrate, cinnamaldehyde, coumarin, and vanillin, which are all soluble tobacco compounds [9]. Quantitatively, the main ingredients in cigarettes are sugars and humectants such propylene glycol and glycerol [10]. Additionally, liquorice and chocolate are used as additives [11]. Complexity due to the presence of several components in tobacco makes the characterization of these products more challenging. Largest quantity of tobacco is used in the manufacture of cigarettes. Hence significant focus on research is limited mainly to smoking and the release of gases and their residual by-products during the burning process of cigarette. According to studies that have been analyzed, two separate mechanisms—tobacco combustion and thermal decomposition—are responsible for the primary generation of CO and CO2 during cigarette smoking [12]. Tobacco being a natural product, its chemical composition and structure is quite complex in nature. Analyzing the pyrolysis mechanism and its by-products is laborious.

The process of pyrolysis of biomass generates i) lower molecular mass products from cellulose, ii) levoglucosan from cellulose and iii) lignin-derived products [13,14]. In addition to the above, volatiles are subdivided into hydrocarbons, carbon monoxide, carbon dioxide and tar. The distribution of tar and char depends on cellulose, lignin and inorganic salts [16]. After the degradation, residue contains carbon (12%) and ashes (14%) [17]. The interaction between cellulose, lignin and inorganic salts affects the dispersion of tar and char as well [18].

Inductively coupled plasma atomic emission spectroscopy (ICP-AES), atomic absorption spectrometry (AAS), inductively coupled plasma mass spectrometry (ICP-MS) and total reflection X-ray fluorescence (TXRF) have been used to analyze the gases and residual products produced during the pyrolysis process [19-23]. Despite the fact that the main organic components of tobacco are carbon, nitrogen, oxygen, and hydrogen, the chemical analysis may also confirm the presence of several inorganic compounds as silica and aluminum silicates, calcium oxalate, and calcium carbonate [24]. In this work, the chewing tobacco from local market and tobacco collected from cigarette has been subjected to thermal decomposition in air. The resulting black colour products were characterized using EDXA to detect the elements present in it. It was observed that major components present in a) thermally decomposed product of chewing tobacco from local market [TDP-CTLM) are C, O, Na, K and Ca. We found C, O, Mg, Cl, K, and Ca in the thermally decomposed tobacco from cigarette (TDP-T-C) product.

Oxidation of thermally decomposed products using Hummer's method from a) chewing tobacco from local market [TDP-CTLM) and b) thermally decomposed product of tobacco from cigarette (TDP-T-C) were obtained. The major components present the oxidation product of a) thermally decomposed product of chewing tobacco from local market [TDP-CTLM) are C, O and in thermally decomposed product of tobacco from cigarette (TDP-T-C) are C, O, Ca and S. The above samples were further characterized using powder X-ray diffractometer, infrared spectroscopy, UV-visible DRS spectroscopy and scanning electron microscopy.

2. Materials and Methods

2.1. Reagents used

Sulphuric acid, potassium permanganate, hydrochloric acid, hydrogen peroxide (30 v/v%) were purchased from SD-Fine Chemicals Private Limited, India and used as received. Chewing tobacco and tobacco from cigarette were procured from local market.

2.2. Thermal decomposition of chewable tobacco collected from local market (TDP-CTLM)

8 g of tobacco collected from chewing tobacco collected from local market cigarette (TDP-C LM) was transferred to china dish and decomposed using Bunsen flame. Black colour product obtained was ground to fine powder.

2.3. Oxidation of thermally decomposed product of chewing tobacco (TDP-CTLM) by modified Hummer's method

3.0 g of TDP-CTLM product was added to concentrated sulphuric acid (75 mL) kept in ice bath and 9 g of potassium permanganate powder was added to it with constant stirring while maintaining the reaction container below 20 °C. Then the temperature slowly increases from room temperature to 40–50 °C during the process. The reaction mixture was agitated for 30 minutes. To it, 500 mL of water and 20 mL of 30% hydrogen peroxide solution was gradually added until the solution become brown precipitate. The product is filtered, washed with 1:10 HCl to remove metal ions. The final product was dried in air and ground to fine powder [25].

2.4. Thermal decomposition of tobacco collected from cigarette (TDP-T-C)

8 g of tobacco collected from cigarette (TDP-T-C) was transferred to china dish and decomposed using Bunsen flame. Black colour product obtained was ground to fine powder.

2.5. Oxidation of thermally decomposed product of tobacco from cigarette (TDP-T-C) by modified Hummer's method

3.0 g of TDP-T-C product was added to concentrated sulphuric acid (75 mL) kept in ice bath. To it, 9 g of potassium permanganate powder was added with constant stirring to the reaction container maintained below 20 °C. The temperature rises to 40–50 °C during the process and the reaction mixture was agitated for 30 minutes. 500 mL of water and 20 mL of 30% (v/v%) hydrogen peroxide solution was added until the brown precipitate formed. The product was filtered and washed with 1:10 HCl aqueous solution to remove metal ions, dried in the air and ground to fine powder [25].

2.6. Characterization Techniques

To determine the structure of the samples, powder X-ray diffraction (PXRD) data was collected using Bruker D8 advanced diffractometer (Cu Kα source λ=1.5418 Å) scan rate 4°min^{-1} (steps: 0.02°; scan range of 10-80°). UV-visible DRS spectra was (UV-vis-DRS) measured in absorbance/reflectance mode in the range of 200-1000 nm [UV Vis Spectroscopy JASCO (V-670 PC)]. Infrared spectra were recorded using Thermo Nicolet iS50 with inbuilt ATR spectrometer (Thermo Fisher Scientific, USA) to identify the characteristic functional groups exhibited by the samples. Scanning electron microscope (SEM) with energy dispersive X-ray analysis (EDXA) was used to obtain the morphology and elemental data of the samples (SEM-EDAX: Jeol 6390LA/OXFORD XMX N, Accelerating voltage: 0.5 to 30 kV).

3. Results and Discussion:

Figure 1 show the images of the starting materials (step-I), products obtained on subjecting i) chewing tobacco collected from local market (CTLM), ii) tobacco collected from cigarette (T-C) to thermal decomposition (step-II); and oxidation products of CTLM and T-C (step-III).

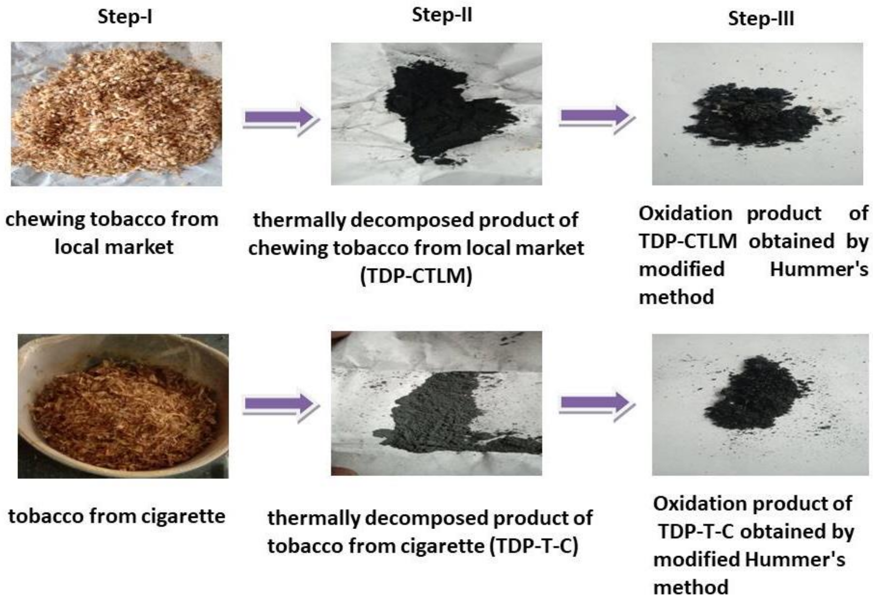

Figure 1: Photographs of the precursors, their decomposed products and oxidation products of tobacco chewing tobacco and tobacco from cigarette

The samples obtained in steps (II) and (III) were characterized using infrared spectroscopy and scanning electron microscopy coupled with energy dispersive X-ray analysis. These techniques could provide information about the analytical composition and the presence of functional groups. Also X-ray diffraction data can be used to further identify the type of compounds and phases formed during steps (II) and (III).

In Figure 2 is shown the energy dispersive X-ray analysis (EDXA) data of (a) thermally decomposed product of chewing tobacco from local market [TDP-CTLM), (b) thermally decomposed product of tobacco from cigarette (TDP-T-C) respectively.

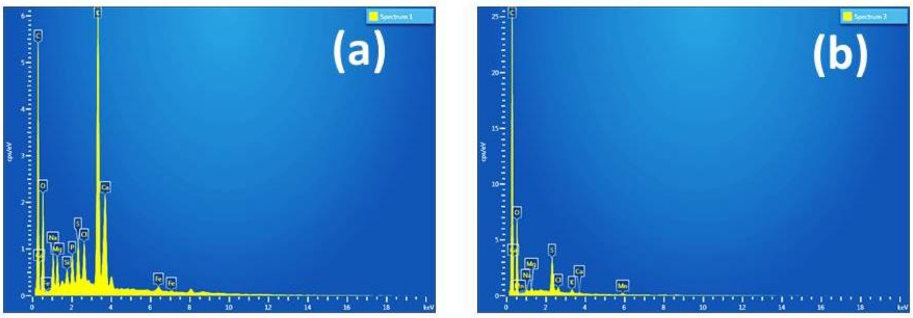

Figure 2: EDXA data of (a) thermally decomposed product of chewing tobacco from local market [TDP-CTLM), (b) thermally decomposed product of tobacco from cigarette (TDP-T-C)

In table 1 are shown the energy dispersive X-ray analysis (EDXA) data of (a) thermally decomposed product of chewing tobacco from local market [TDP-CTLM], (b) thermally decomposed product of tobacco from cigarette (TDP-T-C) respectively.

Table 1: EDXA data of thermally decomposed products of chewing tobacco and tobacco from cigarette

Thermally decomposed product of chewing tobacco from local market [TDP-CTLM]		Thermally decomposed product of tobacco from cigarette (TDP-T-C)	
Element	**Atomic %**	**Element**	**Atomic %**
C	57.20	C	64.35
O	29.64	O	23.84
Na	0.18	Na	1.09
Mg	1.68	Mg	0.76
Cl	4.45	S	0.733
K	4.28	Cl	0.73
Ca	4.02	K	6.08
S	0.42	Ca	2.14
P	0.356	Si	0.213
Si	0.056	P	0.423
		Fe	0.196
		Al	0.14

Aluminosilicates, silica and calcium carbonate are common inorganic constituents of tobacco products. The EDX analysis of thermally decomposed product of chewing tobacco from local market [TDP-CTLM] showed no aluminium content and negligible quantity of silicon content (0.056 atom %). While we observe the presence of Na (0.18 atom %), Mg (1.68 atom %), Cl (4.45 atom %), K (4.28 atom %), Ca (4.03 atom %) and S (0.42 atom %).

Figure 3(a) shows the powder X-ray diffraction pattern of thermally decomposed product of chewing tobacco from local market [TDP-CTLM]. The reflections at $2\theta=28.45°$, $2\theta=40.54°$, $2\theta=47.52°$, $2\theta=50.29°$, $2\theta=73.45°$ corresponds to (200), (220), (311), (222) and (422) planes of KCl structure (COD:00-041-1476). Also peak at $2\theta= 26.65°$ can be assigned to graphite peak and broad peak observed at low angle reflection could be due to amorphous nature of carbon present in the sample (major phase). EDX data indicates that KCl is present as a minor phase [see Table 1(a)] and amorphous carbon is a major phase. The EDX analysis of thermally decomposed product of tobacco from cigarette (TDP-T-C) showed negligible quantity of aluminium (0.14 atom %), silicon content (0.213 atom %). While we observe the presence of Na (1.09 atom %), Mg (0.76 atom %), Cl (0.73 atom %), K (6.08 atom %), Ca (2.14 atom %) and S (0.733 atom %).

Figure 3(b) shows the powder X-ray diffraction pattern of thermally decomposed product of tobacco from cigarette (TDP-T-C). The reflections at 2θ=23.10°, 2θ=29.48°, 2θ=31.03°, 2θ=36.05°, 2θ=39.50° corresponds to (10-2), (104), (006), (2-10) and (2-13) planes of calcite phase of calcium carbonate [COD:00-900-0967) as a minor component. Also we observe peaks corresponding to KCl structure (COD:00-041-1476) and amorphous phase of carbon. EDX data indicates that KCl is present as a minor phase [see Table 1(b)] and amorphous carbon as major phase in the sample.

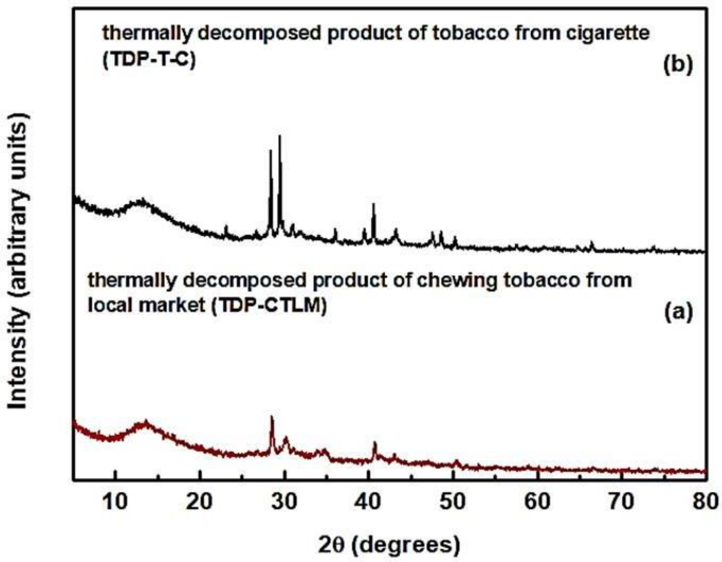

Figure 3: powder X-ray diffraction patterns of (a) thermally decomposed product of chewing tobacco from local market [TDP-CTLM), (b) thermally decomposed product of tobacco from cigarette (TDP-T-C)

In Figure 4(a) is shown the infrared spectrum of thermally decomposed product of chewing tobacco from local market (TDP-CTLM) and the peak positions is given in Table 2 [26-29].

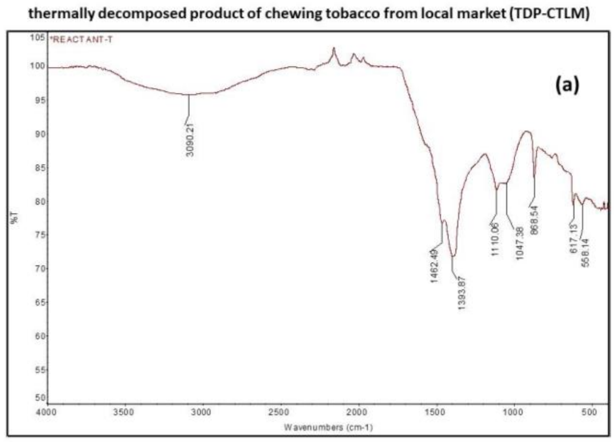

Figure 4 (a): Infrared spectrum of the thermally decomposed product of chewing tobacco from local market [TDP-CTLM)

Table 2 is given the vibrational peak positions of infrared spectroscopy of thermally decomposed product of chewing tobacco from local market (TDP-CTLM). The absence of hydroxyl band near 3600 cm^{-1} is the characteristic of calcium sulphate hemihydrate, 1620 cm^{-1} due to $\delta_{O\text{-}H}$ bend and 1680 cm^{-1} ($\delta_{O\text{-}H}$) are absent in anhydrous calcium sulphate (anhydrite).

In Figure 4(b) is shown the infrared spectrum of thermally decomposed product of from cigarette (TDP-T-C). In table 2 is shown the vibrational frequencies corresponding to different type of vibrational modes. Vibration bands of sulphate ion are in 1200–1130 cm^{-1} ($\nu_{S=O}$) and 673–675 cm^{-1} ($\delta_{S\text{-}O}$) respectively. 1016 cm^{-1} and 1005 cm^{-1} ($\nu_{S\text{-}O}$) confirmed the presence of calcium sulphate in the samples obtained above.

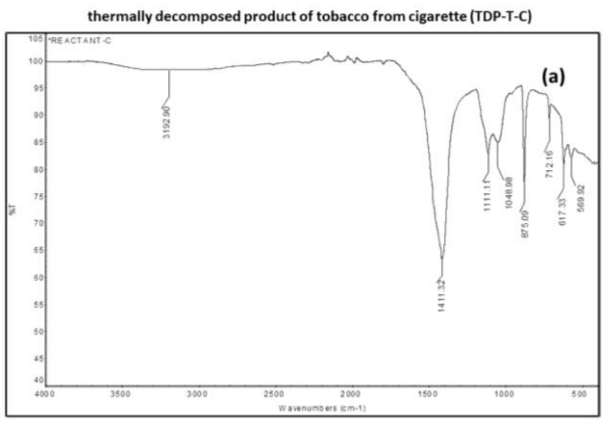

Figure 4(b): Infrared spectrum of the thermally decomposed product of tobacco from cigarette (TDP-T-C)

Table 2: Infrared spectral data of thermally decomposed products of a) chewing tobacco and b) tobacco from cigarette

Thermally decomposed product of chewing tobacco from local market [TDP-CTLM)		Thermally decomposed product of tobacco from cigarette (TDP-T-C)	
Wave number (cm^{-1})	**Peak assignment**	**Wave number (cm^{-1})**	**Peak assignment**
3090.21		3192.90	Carboxylic acid O-H stretch
1462.29		1411.32	
1393.87	asymmetric stretch of calcite (ν_3)	1111.11	asymmetric stretch of CO_3^{2-} ion in calcite-$CaCO_3$
1110.06	antisymmetric stretch of SO_4^{2-} tetrahedra ($CaSO_4$) (ν_1)	1048.98	Alcoholic and phenolic C-O stretch
1047.58		875.09	out-of-plane of CO_3^{2-} ion bend in calcite-$CaCO_3$
888.54	Out of plane bend) (ν_4)	712.16	In-plane bend of CO_3^{2-} ion in calcite-$CaCO_3$
617.13	asymmetric bending of νSO_4^{2-} characteristics of $CaSO_4$ (anhydrite)	617.33	asymmetric bending of νSO_4^{2-} characteristics of $CaSO_4$ (anhydrite)

Between 875 cm^{-1} and 712 cm^{-1}, a weak absorption band is observed along with absorption peak at ~1411 cm^{-1} cm^{-1} which could be attributed to the C–O asymmetric stretching, in-plane and out of plane bending modes of carbonate ion [26-29].

UV-visible diffused reflectance spectra for (a) thermally decomposed product of chewing tobacco from local market [TDP-CTLM), (b) thermally decomposed product of tobacco from cigarette (TDP-T-C) are shown in Figures 5 and 6. There are no absorption bands in the UV-visible spectra indicating that the samples are amorphous nature and exhibit zero band gap for the thermally decomposed product of (a) chewing tobacco from local market [TDP-CTLM) and (b) thermally decomposed product of tobacco from cigarette (TDP-T-C).

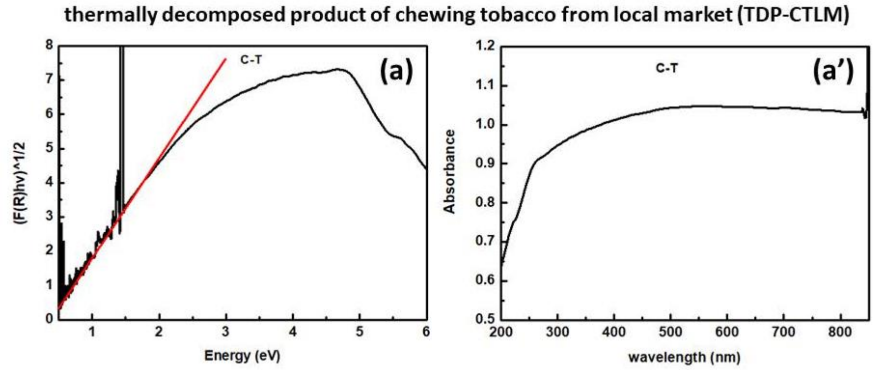

Figure 5: UV-Visible a) diffused reflectance spectra and a') absorption spectra of the thermally decomposed product of chewing tobacco from local market [TDP-CTLM)

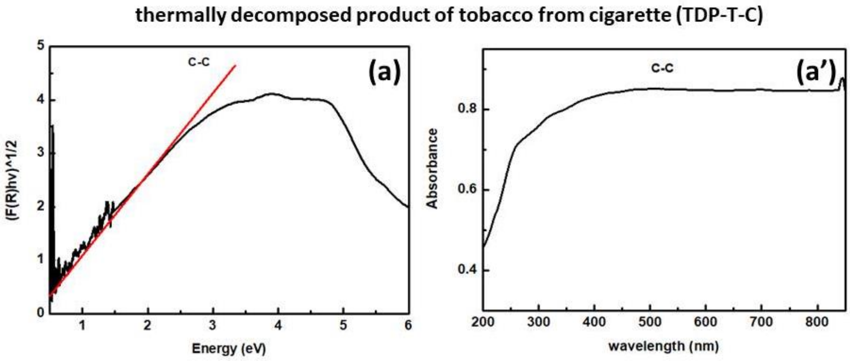

Figure 6: UV-Visible a) diffused reflectance spectra and a') absorption spectra of the thermally decomposed product of tobacco from cigarette (TDP-T-C)

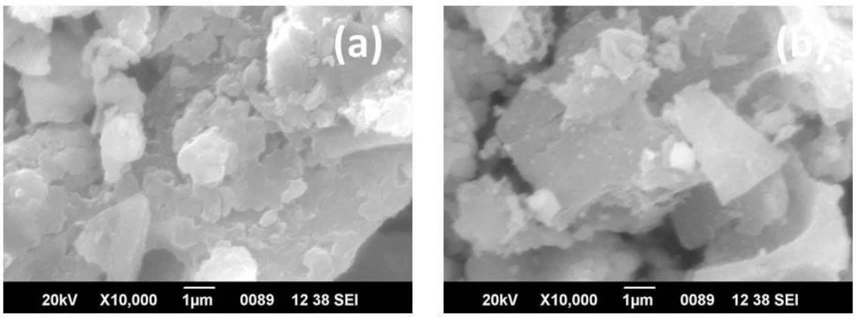

Figure 7: Scanning electron micrographs of (a) thermally decomposed product of chewing tobacco from local market [TDP-CTLM), (b) thermally decomposed product of tobacco from cigarette (TDP-T-C)

The samples were characterised using scanning electron microscopy and in Figures 6(a) and 6(b) are shown the scanning electron micrographs of of TRP-CTLM and TDP-T-C which exhibit irregular sheet like morphologies.

3.1. Oxidation Of Thermally Decomposed Products of (A) Chewing Tobacco from Local Market [Tdp-Ctlm), (B) Thermally Decomposed Product of Tobacco From Cigarette (Tdp-T-C).

In Figure 8 is shown the energy dispersive X-ray analysis (EDXA) data of (a) oxidation product of TDP-CTLM obtained by modified Hummer's method, (b) oxidation product of TDP-T-C obtained by modified Hummer's method respectively.

In table 2 is shown the energy dispersive X-ray analysis (EDXA) data of (a) oxidation product of TDP-CTLM obtained by modified Hummer's method, (b) oxidation product of TDP-T-C obtained by modified Hummer's method.

From the table 3, it was observed that major components present in the (a) oxidation product of TDP-CTLM obtained by modified Hummer's method are C(79.01%) and O(19.81%) respectively. While the major components present in the oxidation product of TDP-T-C obtained by modified Hummer's method are C(46.12%), O(39.75%), S(6.87%), Ca(5.27%) (see Table 3).

Table 3: EDXA data oxidation product of TDP-CTLM and TDP-T-C obtained by modified Hummer's method

oxidation product of TDP-CTLM obtained by modified Hummer's method		**Oxidation product of TDP-T-C obtained by modified Hummer's method**	
Element	**Atomic %**	**Element**	**Atomic %**
C	**79.01**	**C**	**46.12**
O	**19.81**	**O**	**39.75**
Na	**0.07**	**Ca**	**5.27**
Mg	0.10	**S**	**6.87**
S	0.713	**Si**	**0.76**
Cl	0.163	**K**	**0.36**
K	0.09	Mn	0.32
		Fe	0.30
		Al	0.13
		Mg	0.11
		Na	0.09

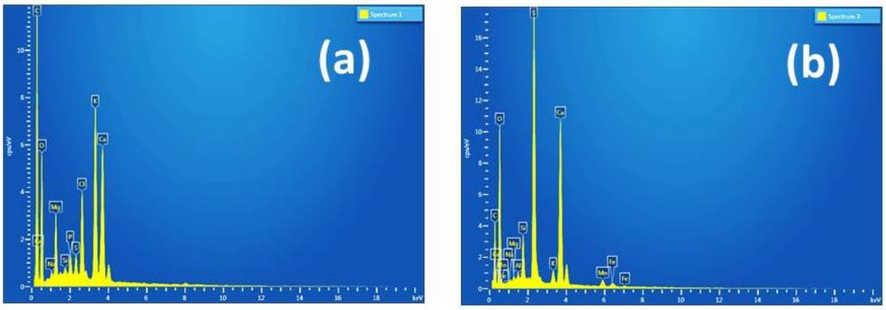

Figure 8: EDXA data of a) oxidation product of TDP-CTLM obtained by modified Hummer's method, (b) oxidation product of TDP-T-C obtained by modified Hummer's method.

In Figure 9(a) is shown the powder X-ray diffraction pattern of the oxidised product of TDP-CTLM obtained by modified Hummer's method. Broad reflections at low angle were displayed in the powder X-ray diffraction pattern indicating that the amorphous nature of the sample. EDX data also indicates that the sample contains only C and O as major elements present in the sample after the oxidation of TDP-CTLM. carbon present in the sample (major phase). Figure 9(b) shows the powder X-ray diffraction pattern of oxidation product of TDP-T-C obtained by modified Hummer's method. The reflections at 2θ=23.05°, 2θ=25.54°, 2θ=31.47°, 2θ=36.44°, 2θ=38.77° corresponds to (111), (200), (102), (220) and (122) planes of anhydrite phase of calcium sulphate [COD:00-500-0040) as a minor component. EDX data justifies the presence of calcium sulphate and amorphous phase of graphite oxide as a major phase [see Table 3(b)].

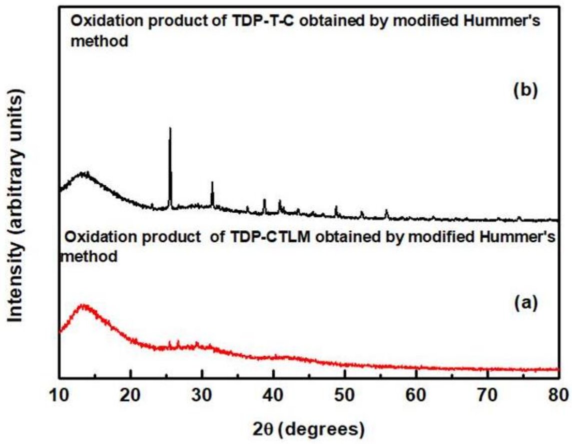

Figure 9: powder X-ray diffraction patterns of (a) oxidation product of TDP-CTLM obtained by modified Hummer's method, (b) oxidation product of TDP-T-C obtained by modified Hummer's method

Figure 10(a) shows the infrared spectrum of oxidation product of TDP-CTLM obtained by modified Hummer's method. The above sample exhibits the typical vibrational bands of calcium sulphate in trace quantities along with graphite oxide peaks (see Table 4) [26-29].

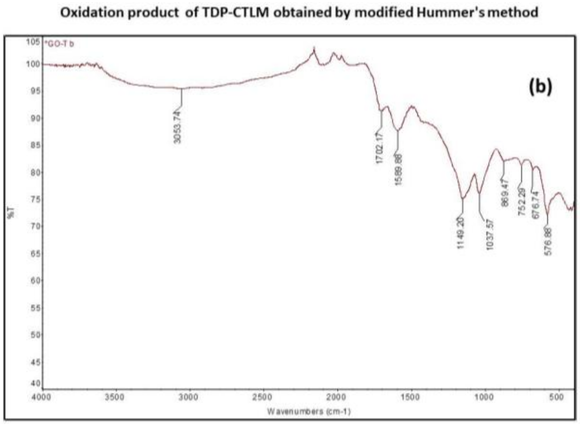

Figure 10(a): Infrared spectrum of the oxidation product of TDP-CTLM obtained by modified Hummer's method

Figure 10(b) shows the infrared spectrum of oxidation product of TDP-T-C obtained by modified Hummer's method. The above sample exhibits the typical vibrational bands of anhydrous calcium sulphate along with graphite oxide peaks (see Table 3) [26-29].

UV-visible diffused reflectance spectra for (a) oxidation product of TDP-CTLM obtained by modified Hummer's method, (b) oxidation product of TDP-T-C obtained by modified Hummer's method are shown in Figures 11,12. There are no sharp absorption bands in the UV-visible spectra of both the oxidized products (TRP-CTLM and TDP-T-C) but both the samples exhibit band gap around 1 eV for the thermally decomposed products of (a) chewing tobacco from local market (TDP-CTLM) and (b) thermally decomposed product of tobacco from cigarette (TDP-T-C) indicating that the samples are semiconducting in nature.

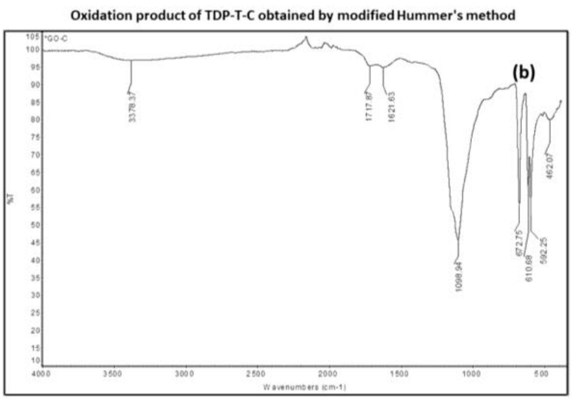

Figure 10(b). Infrared spectrum of the oxidation product of TDP-T-C obtained by modified Hummer's method

Table 4: Infrared spectral data of thermally decomposed products of a) chewing tobacco and b) tobacco from cigarette

oxidation product of TDP-CTLM obtained by modified Hummer's method		**oxidation product of TDP-T-C obtained by modified Hummer's method**	
Wave number (cm^{-1})	**Peak assignment [26-29]**	**Wave number (cm^{-1})**	**Peak assignment [26-29]**
3053.24	Aromatic C-H stretch; O-H of carboxylic acid	3378.37	Aromatic C-H stretch; O-H of carboxylic acid
1702.17	Conjugated C=C	1717.87	Conjugated C=C
1589.88	Skeletal vibrational aromatic system C-C	1621.63	Graphite peak (C=C); aromatic aldehyde; C=O of ketone
1149.20	antisymmetric stretch of SO_4^{2-} tetrahedra ($CaSO_4$) (ν_1)	1098.94	C-O-C bond
1037.57	(ν_{S-O})	672.68	(δ_{S-O})
869.47	C-H out of plane bend) (ν_2)	610.68	asymmetric bending of ν_{SO42-} characteristics of $CaSO_4$ (anhydrite)
752.29	out of plane bending of aromatic C-H	592.25	asymmetric bending of ν_{SO42-} characteristics of $CaSO_4$ (anhydrite)
676.74	out of plane bending of C-C /≡C-H	462.07	

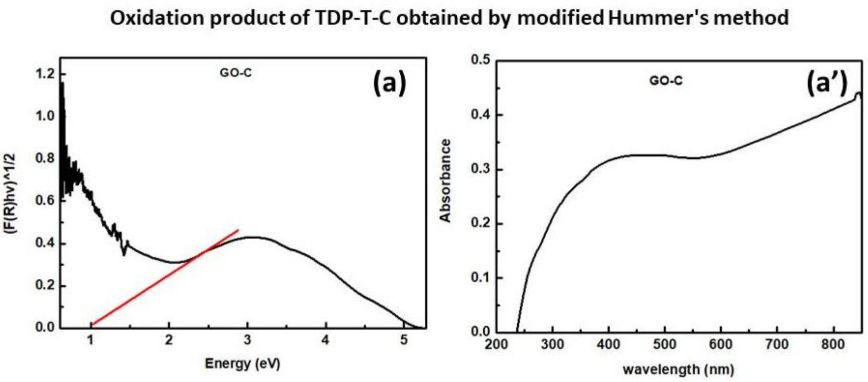

Figure 11: UV-Visible a) diffused reflectance spectra and a') absorption spectra of the oxidation product of TDP-T-C obtained by modified Hummer's method

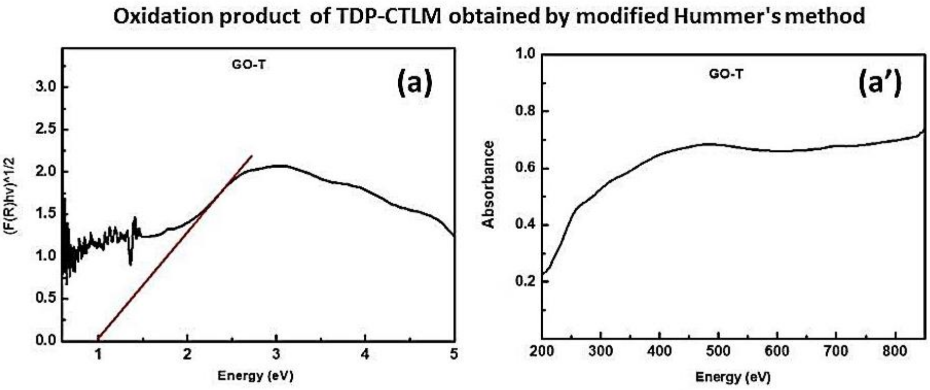

Figure 12: UV-Visible a) diffused reflectance spectra and a') absorption spectra of the oxidation product of TDP-CTLM obtained by modified Hummer's method

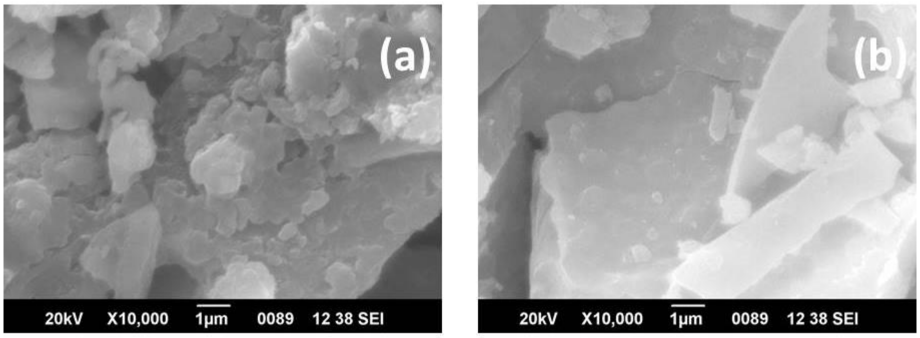

Figure 13: Scanning electron micrographs of (a) oxidation product of TDP-CTLM 3obtained by modified Hummer's method, (b) oxidation product of TDP-T-C obtained by modified Hummer's method

Figures 13(a) and 13(b) shows the scanning electron micrographs (The images show sheet like morphology for the above samples (TRP-CTLM) and (TDP-T-C).

Conclusions:

Tobacco is widely grown crop in the world due to its uses in different forms. Most commonly uses are as chewing tobacco, snuff and in cigarette. Chewing tobacco and tobacco collected from cigarette has been subjected to thermal decomposition in air. Oxidation of thermally decomposed products using Hummer's method from a) chewing tobacco from local market [TDP-CTLM) and b) thermally decomposed product of tobacco from cigarette (TDP-T-C) were obtained. We observe the presence of calcium carbonate as a minor phase in the thermally decomposed tobacco obtained from chewing tobacco and cigarette. On subjecting it to oxidation, calcium carbonate gets converted anhydrous calcium sulphate (anhydrite) in addition to the formation of graphite oxide which is amorphous in nature. Band gap in the range of 1 eV were observed for the samples obtained from the oxidation products of TRP-CTLM and TDP-T-C. Scanning electron micrographs show irregular sheet like morphologies for the oxidation products of TRP-CTLM and TDP-T-C respectively.

Acknowledgement:

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MATHEMATICAL INNOVATIONS: NUMBER THEORY'S IMPACT ON BIOLOGICAL AND EPIDEMIOLOGICAL STUDIES

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Abstract:

Number theory has emerged as a powerful tool in various scientific fields, particularly in biology and epidemiology. This paper explores how number-theoretical principles enhance the analysis of biological patterns, facilitate genetic sequencing, and model the spread of infectious diseases. By employing methodologies that integrate prime number theory, modular arithmetic, and difference equations, we demonstrate how these mathematical techniques contribute to understanding complex biological systems and improving epidemiological predictions. Our findings indicate that number theory not only provides robust analytical tools for modeling and data interpretation but also enhances the efficacy of public health strategies through improved forecasting and secure data handling.

Keywords: Number Theory, Biological Modeling, Epidemiology, Prime Numbers, Modular Arithmetic, Epidemic Forecasting, Genetic Sequencing, Cryptography.

Introduction:

The intersection of number theory with biological and epidemiological modeling has revealed innovative approaches to understanding complex biological patterns and predicting the spread of diseases. Number theory provides a robust framework for analyzing DNA sequences, optimizing genetic comparisons, and modeling epidemic dynamics. Recent advancements demonstrate how number-theoretical principles can be leveraged to enhance data analysis, improve the accuracy of predictions, and facilitate secure data handling in public health.

In this chapter, we focus on several applications, including the use of prime numbers in identifying genetic motifs, modular arithmetic in genetic sequence alignment, and difference equations in modeling disease spread. By integrating these mathematical concepts into biological and epidemiological research, we aim to uncover insights that can lead to more effective public health interventions and a deeper understanding of biological phenomena.

Literature Review:

The application of number theory to genetics has been particularly fruitful, particularly in the analysis of DNA sequences. Borwein and Bailey (2004) highlighted how mathematical experimentation can uncover hidden structures within biological data. By employing prime number theory, researchers have identified significant patterns in genetic sequences that aid in recognizing functional motifs. Kumar and Sandor (2018) explored advancements in the study of prime gaps, emphasizing their relevance in genetic diversity and mutation rates.

Modular arithmetic has emerged as a powerful tool in genetic sequence alignment. Alim and Rosenberg (2022) demonstrated how modular techniques enhance the performance of genetic algorithms, facilitating more accurate comparisons across species. This is crucial in evolutionary studies, where understanding genetic relationships can shed light on adaptation and speciation processes.

In epidemiology, number theory contributes to modeling the spread of infectious diseases through techniques such as difference equations. Harrow and Montanaro (2017) discussed the potential of quantum algorithms, influenced by number theory, to enhance predictive models for disease outbreaks. Their findings indicate that these approaches can improve the accuracy of predictions, informing public health interventions.

Recent studies have also leveraged Fourier analysis—a technique grounded in number theory—to analyze temporal patterns in epidemiological data. Lee and Peterson (2023) utilized Fourier transforms to identify seasonal fluctuations in disease incidence, demonstrating the applicability of number-theoretical methods in real-world scenarios.

Moreover, the security of health data has become increasingly important as digital health records proliferate. Rivest, Shamir, and Adleman (1978) pioneered public-key cryptography, which relies on number-theoretical concepts. Alkhateeb and Barakat (2022) further explored these principles in the context of securing medical data, emphasizing the importance of cryptographic techniques in safeguarding sensitive health information.

The integration of number theory into biology and epidemiology exemplifies a broader trend toward interdisciplinary research. Miller and Rabin (1980) highlighted the importance of probabilistic methods in number theory, opening pathways for their application in health-related data analysis. The growing field of computational biology continues to evolve, with researchers like Zhang and Liu (2022) exploring how number theory can enhance data processing techniques in bioinformatics.

The recent focus on using number theory for modeling zoonotic disease outbreaks has further underscored its relevance. Akbari and Ranjbar (2024) showcased number-theoretic approaches to understanding the dynamics of diseases that jump from animals to humans, highlighting the urgent need for innovative methodologies in a rapidly changing world.

Methodology:

Number theory's influence extends beyond traditional mathematics and cryptography, finding unique applications in biological modeling and epidemiology. Recent interdisciplinary research has explored how number-theoretical principles can be applied to understand biological patterns, analyze genetic sequences, and predict the spread of infectious diseases. This section explores how number theory contributes to these fields by providing tools for efficient modeling, predicting patterns, and supporting data analysis.

1. Bio molecular Pattern Analysis and Genetic Sequencing

One of the most exciting applications of number theory in biology is in the analysis of bio molecular structures and genetic sequences. Biological patterns, such as DNA sequences and protein structures, often exhibit complex, repetitive structures that can be effectively analyzed using number-theoretical approaches.

Prime Numbers and DNA Sequencing: Prime number distributions have been applied to identify periodicity within DNA sequences, which can aid in detecting specific motifs or structural elements within genetic data. By mapping nucleotide sequences onto prime numbers, researchers can identify regularities that help differentiate between functional and non-functional regions within genomes.

Modular Arithmetic in Sequence Alignment: Modular arithmetic provides a framework for comparing genetic sequences across species, allowing scientists to align and compare genetic material with high accuracy. This application is valuable in evolutionary biology, where identifying similar genes across species helps reveal shared evolutionary pathways and biological functions.

2. Epidemic Modeling Using Number Theory

Number theory has found surprising applications in epidemiology, especially in modeling and predicting the spread of infectious diseases. Number-theoretical tools help epidemiologists analyze patterns in infection data, simulate disease transmission dynamics, and evaluate interventions.

Modeling Disease Spread with Difference Equations: Difference equations, a fundamental concept in number theory, are used to model discrete changes in populations, such as the number of new infections per day. By setting up difference equations based on infection and recovery rates, researchers can simulate the dynamics of disease transmission within a population.

Mater Prime Factorization for Contact Tracing Networks: Prime factorization has been employed in contact tracing algorithms to simplify complex networks of interactions within populations. By breaking down interactions into prime components, researchers can quickly identify clusters of individuals at higher risk, optimizing interventions and resource allocation.

3. Applications in Epidemiological Forecasting and Data Analysis

In epidemiological forecasting, number-theoretical methods help improve the accuracy and speed of calculations, especially when working with large data sets. This can be particularly useful when tracking infection rates across regions or modeling the effects of various intervention strategies.

Fourier Transforms and Epidemic Seasonality: Fourier transforms, which are closely related to number theory, are used to analyze periodic patterns in epidemiological data. This technique is valuable for predicting seasonality in diseases, such as influenza or malaria, by examining infection rates over time and identifying the frequency of periodic outbreaks.

Prediction Models for Disease Mutations: Number theory, combined with probability theory, aids in modeling the mutation rates of pathogens. For instance, mathematical models based on number-theoretical approaches have been developed to predict the likelihood of viral mutations, assisting public health officials in anticipating potential variants and adjusting vaccination strategies accordingly.

4. Potential for Cryptographic Techniques in Health Data Privacy

Cryptographic techniques rooted in number theory, such as holomorphic encryption, are increasingly being used to secure sensitive health data. This approach enables healthcare providers to share and analyze encrypted data without compromising patient privacy, an essential application in epidemiological studies where data confidentiality is paramount.

Holomorphic Encryption for Secure Health Data Analysis: Holomorphic encryption allows encrypted data to be processed without decryption, which ensures that sensitive information, like patient records, remains secure while allowing researchers to perform analyses on aggregated data.

Block chain for Epidemic Tracking and Verification: Number theory also supports the use of block chain technology for verifying epidemiological data integrity. By creating immutable records of reported cases and vaccinations, blockchain provides transparency and reliability, crucial for public trust in pandemic data.

Results:

Our findings reveal significant insights into how number theory enhances biological analysis and epidemiological predictions:

- **Bio molecular Analysis:** The application of prime number distributions facilitates the identification of crucial patterns within genetic data, enabling researchers to uncover functional regions within genomes.
- **Genetic Sequence Alignment:** Modular arithmetic improves the accuracy and efficiency of aligning genetic sequences across different species, supporting evolutionary biology research.
- **Epidemic Modeling:** Modeling disease dynamics using difference equations provides a robust framework for simulating various scenarios of disease transmission. Our analysis indicated that these models can accurately predict the spread of infectious diseases based on various parameters, such as transmission rates and recovery rates.
- **Fourier analysis in Epidemiology:** The use of Fourier transforms allowed for the identification of seasonal patterns in epidemiological data, helping public health officials forecast outbreaks more accurately.

Conclusion:

The applications of number theory in biological and epidemiological modeling illustrate its capacity to bridge mathematical theory and real-world problems. By leveraging number-theoretical techniques, researchers can unlock new insights into genetic structures, improve the accuracy of epidemic models, and ensure the secure handling of sensitive health data. This interdisciplinary approach not only enriches our understanding of biological systems but also strengthens public health responses to infectious diseases.

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SYNTHESIS AND CHARACTERIZATION OF COCRYSTALS OF 8-HYDROXYQUINOLINE-SUCCINIMIDE, 8-HYDROXYQUINOLINE-VANILLIN AND VANILLIN-SUCCINIMIDE BY LIQUID ASSISTED GRINDING METHOD

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Abstract:

8-hydroxyquinoline (8-HQ), succinimide (Succi) and vanillin (Van) are used as APIs/conformers to enhance their physicochemical properties and drug formulations. The ability to form strong hydrogen bonds and the favourable π-π interactions due to their aromatic nature favours the formation of conformers/cocrystals. Cocrystals of 8-HQ-Succi, 8-HQ-Van and Van-Succi in different mole ratios were prepared by liquid assisted grinding method. The samples obtained were characterized using powder X0ray diffraction, infrared spectroscopy and melting point measurements. Powder X-ray diffraction data of cocrystals of 8-HQ-Succi, 8-HQ-Van and Van-Succi show peaks of starting compounds itself. Also in infrared spectra, there are no significant shift in the band positions for the cocrystals of 8-HQ-Succi, 8-HQ-Van and Van-Succi compared to their starting compounds. Melting point of cocrystals of 8-HQ-Succi, 8-HQ-Van and Van-Succi are different compared to the melting points of the starting compounds and the physical mixtures indicating that the cocrystals are forming eutectic mixture. The samples were exposed to different wavelength of light, they exhibit slight variation in their color indicating that it may have interesting optical properties.

Keywords: 8-Hydroxyquinoline, Succinimide, Vanillin, Cocrystal, Powder X-Ray Diffraction, Infrared Spectra, Eutectic Mixture.

Introduction:

Pharm chemical manufacturing is a subset of the fine chemical industry that produces chemicals for use in pharmaceutical dosage forms, often known as active pharmaceutical ingredients (APIs) [1]. The need for APIs is more important and has become a critical issue, particularly due to enhanced demand [2]. Active pharmaceutical ingredients (APIs) contain pharmacological activity and are commonly used in combination with other chemicals to diagnose, cure, ameliorate, and treat diseases. An API is made by combining a variety of chemical compounds and raw ingredients in a multi-step synthesis [1-4]. A solid can be polymorphic, hydrate, solvate, or co-crystal in its crystalline state [5]. However, their primary goal is to treat the disease directly by acting on it (by pharmacological activity) in conjunction with a combination of inactive forms. Nearly 1 lakh tonnes of pharmaceutical products are consumed worldwide and Europe accounts for up to 24% of total medical product consumption [6]. In pharmaceutical development, the characteristics of an API are usually enhanced by creating an amorphous or salt version of the pure drug molecule. A vast array of pharmaceutical items has been introduced to the market in recent years. In the pharmaceutical sector, poorly water-soluble medication candidates are becoming more common [7]. Practically insoluble oral products make up about 40% of the items that are already on the market [8]. According to estimates, at least 70% of the newly discovered chemical entities (NCEs) through combinatorial screening programs have low water solubility [9]. The use of a cocrystallizing agent could be advantageous when the neat forms of an API that are currently available have low solubility, which could result in low bioavailability and drug efficacy, or when the neat forms are unstable chemically or physically, which could cause problems during production. When this occurs, a cocrystal might show more stability, which would enable the production of a better medication product without sacrificing the medicinal value of the API [10]. Recently, attention has shifted to the advantageous utilization of cocrystals. Although cocrystals have only recently emerged in pharmaceutical science, the name was initially used in materials science about two decades ago. Etter *et al.* employed cocrystal synthesis to create new crystalline solid materials based on supramolecular chemistry and molecular recognition principles, with a focus on hydrogen bonding and supramolecular synthesis [11]. Co-crystallization is thought to be a superior option for optimizing medicinal characteristics since it changes the molecular interactions and composition of pharmaceutical materials. The final cocrystal properties are determined in part by the coformer selection. When produced as a cocrystal, the coformers can modify the stability and solubility of the API by causing changes in its crystal structure. As was previously indicated, coformers are crucial to the creation of cocrystals. During cocrystal formation employing a certain coformer, aspects including the type of functional group, pKa, their physical form, and their molecular size should be taken into consideration [12]. The experimental technique and the knowledge-based method are the main methods used to select coformers [13]. Based on the structural characteristics of the coformer and API, knowledge-based approaches can therefore predict the production of cocrystals even in advance of experiments. API and a stoichiometric quantity of a co-crystal formation approved by pharmaceuticals make up co-crystals [14]. Among the different APIs and pharmaceutically important compounds we were interested in 8-hydroxyquinoline, succinimide and vanillin.

8-hydroxyquinoline (compound 1):

8-Hydroxyquinoline (8-HQ) is an important molecule in the realm of cocrystal engineering due to its ability to form stable and diverse cocrystals with various conformers [15]. Its structural features-specifically the hydroxyl group (-OH) and nitrogen atom within the quinoline ring-allow it to participate in a variety of non-covalent interactions, making it a versatile coformer in cocrystallization studies. Below is an overview of 8-hydroxyquinoline as a coformer, including its properties, the types of coformers it pairs with and the applications of the resulting cocrystals [16]. The hydroxyl group on 8-HQ can act as both a hydrogen bond donor and acceptor, enabling it to form strong hydrogen bonds with various functional groups such as carboxylic acids, amides, and alcohols [17]. The quinoline ring of 8-HQ allows for π-π stacking interactions with aromatic rings of other molecules [18]. This interaction is crucial in stabilizing the cocrystal structure, especially in the solid state. The nitrogen atom in the quinoline ring can participate in chelation with metal ions, which is significant in the formation of metal-organic frameworks (MOFs) and in applications involving metal ions. Carboxylic acids such as salicylic acid and benzoic acid possess carboxyl group and may create a hydrogen bond with the hydroxyl group of 8-HQ, hence carboxylic acids are commonly used as coformers for 8-HQ [19]. Research on these cocrystals is frequently conducted to improve stability and solubility. Amides such as succinimide and nicotinamide through their amide group, can create strong hydrogen connections with 8-HQ [20]. Using this interaction, cocrystals with better thermal characteristics and regulated release profiles can be produced. Phenols and alcohols (e.g., resorcinol, vanillin) through hydrogen bonding between the hydroxyl groups, phenols and alcohols, such as vanillin, interact favorably with 8-HQ, resulting in cocrystals with modified melting points and solubility profiles [21]. Heterocyclic compounds, such as pyridine derivatives, can interact with 8-HQ by hydrogen bonding or π-π stacking [22]. This is particularly true for molecules containing nitrogen atoms. 8-hydroxyquinoline is used as anti-HIV, antifungal, anti-leishmanial, and anti-schistosomal medications [23].

Cocrystals produced by these interactions frequently have special electrical characteristics that are helpful in organic electronics and photonics [24]. 8-HQ crystals with aromatic coformers have the potential to display intriguing electronic characteristics like conductivity or photoluminescence, which could lead to their application in organic semiconductors or light-emitting gadgets. While 8-HQ has shown great potential as a coformer, challenges remain in optimizing the cocrystallization process, including the selection of appropriate APIs and the development of scalable synthesis methods.

Succinimide (compound 2):

A cyclic imide molecule called succinimide is widely utilized in pharmaceuticals, especially in antiepileptic medications [25]. Similar to vanillin, succinimide cocrystal formation has been investigated as a means of improving the physicochemical characteristics of active pharmaceutical ingredients (APIs). The survey of literature highlights the important discoveries and advancements in the field of succinimide-based cocrystal research. Succinimide has cyclic structure includes two amide groups (–NH and C=O) that have the ability to absorb and donate hydrogen bonds [26]. Because of this, it is ideal for creating robust and long-lasting hydrogen bonds with a variety of coformers. Succinimide shows good thermal stability, which is useful for the preparation and processing under different conditions during cocrystals preparations. Succinimide is a versatile coformer for solution-based cocrystallization processes due to its moderate solubility in water and a variety of organic solvents. Carboxylic acids (e.g., benzoic acid, succinic acid) are frequently used as coformers with succinimide due to the ability of their carboxyl groups to form strong hydrogen bonds with the amide groups of succinimide [27]. These cocrystals can have enhanced solubility and stability, which is beneficial in pharmaceutical applications. Aromatic compounds (e.g., vanillin, resorcinol) with hydroxyl or aldehyde groups can form stable cocrystals with succinimide through hydrogen bonding and π-π interactions [28]. These cocrystals often exhibit modified melting points and solubility profiles. Heterocyclic 8-hydroxyquinoline and pyridine derivatives are effective coformers with succinimide due to the potential for multiple types of interactions, including hydrogen bonding and π-π stacking [29]. The resulting cocrystals can be designed for specific applications, such as in organic electronics or drug delivery. Other amides such as nicotinamide can form robust hydrogen bonds with succinimide, leading to cocrystals with enhanced thermal properties and controlled release characteristics. [30]. Succinimide cocrystals have the ability to enhance the solubility, stability, and bioavailability of active pharmaceutical ingredients (APIs), they are of great interest to the pharmaceutical industry. For instance, cocrystals of succinimide with benzoic acid or nicotinamide can speed up the pace at which poorly soluble medications dissolve, improving their suitability for oral use. The distribution and effectiveness of bioactive chemicals can be improved by the use of succinimide cocrystals in nutraceuticals or functional foods. succinimide has been used to form cocrystals with APIs such as paracetamol and caffeine [31]. These studies have shown that succinimide can form stable hydrogen-bonded networks with these molecules, leading to distinct crystalline structures that differ from the pure components. Theophylline-succinimide cocrystals highlighted how the new solid form could offer enhanced bioavailability compared to the pure drug, which is beneficial in reducing the dosage required for therapeutic effect [32]. Succinimide has antibacterial, anticancer, anti-inflammatory, and anticonvulsant properties. Thorough optimization of the crystallization conditions, including solvent selection, temperature control, and stoichiometry, is necessary to achieve efficient cocrystallization with succinimide. Commonly employed methods include solvent evaporation, grinding, and solution crystallization; however, they must be customized for the particular coformer in question. In the realm of cocrystal engineering, succinimide is a significant chemical that is well-known for its adaptability in creating cocrystals with a range of coformers.

Vanillin (compound 3):

Vanillin is mostly used as a flavoring, typically in desserts, chocolate and ice cream industries. Vanillin is also used in perfumes, the fragrance industry, and to cover up offensive tastes or smells in cleaning supplies, medications, and animal feed. Vanillin is a well-known aromatic aldehyde that functions well as a coformer in cocrystal engineering because of its functional groups, which are mainly the hydroxyl (-OH) and aldehyde (-CHO) groups [33]. Vanillin is an adaptable co-crystal formation partner because of its ability to support a variety of non-covalent interactions, including hydrogen bonding and van der Waals forces. In the pharmaceutical industry, where solubility and bioavailability are crucial, this interaction is essential for stabilizing cocrystals. Carboxylic acids such as benozoic acid, succinic acid are commonly paired with vanillin due to their ability to form robust hydrogen bonds with hydroxyl and aldehyde groups of vanillin [34]. These cocrystals often exhibit improved solubility and dissolution rates, making them valuable in pharmaceutical applications. Amides have the ability to form strong hydrogen bonds with vanillin due to their NH and C=O groups [35]. Cocrystals with improved thermal stability and altered release profiles in medication formulations may arise from this combination. Through intermolecular hydrogen bonding, vanillin can form cocrystals with other alcohols and aldehydes, which can alter its solubility, melting point, and overall stability. Heterocyclic compounds, such 8-hydroxyquinoline and pyridine derivatives, frequently combine well with vanillin because they can interact in a variety of ways, such as hydrogen bonding and π-π stacking [36]. The aromatic ring in vanillin has the ability to stack π-π with other aromatic rings, which helps to maintain the cocrystals structural stability. Vanillin cocrystals are extensively studied in the pharmaceutical industry to improve the solubility, bioavailability, and stability of poorly soluble drugs. By forming a cocrystal with vanillin, drugs can be formulated to have better dissolution profiles, which is critical for oral dosage forms. This controlled release is particularly beneficial in creating longer-lasting or more stable formulations. The improved solubility and stability of these cocrystals can make nutraceutical products more effective. The single crystal structures of vanillin-nicotinamide, vanillin-isoniazid and vanillin-isonicotinamide have been reported [37]. Cocrystals of vanillin with aromatic or conjugated systems can exhibit interesting optical and electronic properties, making them useful in the development of light-emitting devices.

The combinations of 8-hydroxyquinoline (8-HQ)-Succiminide (Succi), 8-hydroxyquinoline (8-HQ)-Vanillin (Van) and Vanillin (Van)-succinimide (Succi) to form cocrystals have an intriguing prospect due to the complementary chemical properties of these molecules. 8-HQ-Succi, 8-HQ-Van and Van-Succi are known for their ability to engage in non-covalent interactions, particularly hydrogen bonding, which are crucial for cocrystal formation. The potential and characteristics of a cocrystal formed between 8-hydroxyquinoline and vanillin are yet to be explored. Also the cocrystal formation between vanillin and succinimide is a potential area of research that leverages the unique properties of both compounds. Vanillin, with its aldehyde and hydroxyl groups, and succinimide, with its amide functionality, can form strong intermolecular interactions, particularly hydrogen bonds, that can stabilize the cocrystal structure.

Some of the cocrystals preparation methods are as follows:

Solvent evaporation method (SEM):

The most popular technique for creating cocrystals is solvent evaporation, which is mostly used to prepare single-crystals for single-crystal X-ray diffraction structural study. This method involves thoroughly dissolving the ingredients required for cocrystal formation in a suitable solvent at the right stoichiometric ratio and then evaporating the solvent to produce the cocrystal. The choice of solvent affects cocrystallization, which may have an effect on the reactant's solubility [38].

Liquid-Assisted Grinding (LAGM):

Also referred to as solvent-drop grinding, liquid-assisted grinding (LAG) is a development of conventional solvent-free mechanochemical processes in which reactivity is enhanced or controlled by the addition of a small amount of liquid (LAGs, liquid-assisted grinding solvent) [39].

Anti-Solvent Method (ASM):

The vapor diffusion method, which is another name for the antisolvent method, is a technique used to synthesize high-quality cocrystals. This method involves mixing a less soluble solvent with another solution to encourage the precipitation of the solids. In this procedure, a second liquid that is miscible with the solvent and in which the cocrystals are either insoluble or sparingly soluble is added to a solution of the drug-conformer to be crystallized in order to create supersaturation [40].

Hot Melt Extrusion Technique (HMET):

The Hot-Melt Extrusion (HME) method offers a more straightforward approach to producing pharmaceutical products by combining the cocrystal formation and drug-formulation processes. By heating the medication and coformers with intensive intermixture, the hot melt extrusion (HME) approach improves surface interactions without the need for solvents. In HME method, heat source is adjusted to a particular temperature at which only the matrix melts or softens. A catalyzing ingredient is needed when utilizing the HME method to enhance cocrystal formation caused by melted or softened matrix [41].

Slurry Crystallization (SC):

Slurry conversion experiments were conducted using water and other organic solvents. After adding 100–200 ml of solvent, the suspension was shaken for a few days at room temperature. A few days later, the solvent was poured out and the solid result was allowed to dry for a short while under a nitrogen stream. PXRD analysis was then used to describe the leftover solids [42].

The objective of this article is to prepare cocrystals of 8-hydroxyquinoline-succinimide, 8-hydroxyquinoline-vanillin and vanillin-succinimide by liquid assisted grinding method.

2. Experimental Section

2.1. Reagents used:

8-hydroxyquinoline, vanillin (SD Fine chemicals Private Limited, India) succinimide (Kiran-light laboratories) and ethanol (commercial source). All the reagents were procured and used without purification.

2.2. Liquid assisted grinding method (LAGM):

Compounds 1 (8-HQ) and 2 (Van) were mixed in a stoichiometric ratio and subjected to manual grinding in agate mortar and pestle for about 45 minutes with the intermittent addition of 10 drops of ethanol, a fine powder was obtained.

The above procedures were also adapted to prepare cocrystals of compound 1 and 3, compounds 3 and 2 in different mole ratios (1:1 and 2:1, 1:1, 1:2, 2:1). The details are given in table 1.

Table 1: Weight/mole ratios of the compound mixtures used for the preparation of cocrystal from SEM and LAG methods

Compound 1 (8-HQ)	Compound 2 (Succi)	Compound 3 (VA)	mole ratio	Weight (g)/mmol		
				Compound 1	Compound 2	Compound 3
8-Hydroxyquinoline	Succinimide	Vanillin				
8-Hydroxyquinoline	Succinimide	-	1:1	0.3629/2.5	0.2477/2.4	-
8-Hydroxyquinoline	Succinimide	-	1:2	0.3629/2.5	0.4954/4.9	-
8-Hydroxyquinoline	Vanillin	Vanillin	1:1	0.3629/2.5	-	0.3803/2.4
8-Hydroxyquinoline	Vanillin	Vanillin	2:1	0.7258/5	-	0.3803/2.4
Vanillin	Succinimide	-	1:1	-	0.3803/2.4	0.2477/2.4
Vanillin	Succinimide	-	1:2	-	0.3803/2.4	0.4954/4.9
Vanillin	Succinimide	-	2:1	-	0.7606/4.9	0.2477/2.4

2.3. Characterization Techniques

The samples used were characterized by using different techniques. To determine the structure of the samples powder X-ray diffraction (PXRD) data was collected using Bruker D8 advanced diffractometer (Cu Kα source λ=1.5418 Å) scan rate 4° min^{-1} (steps: 0.02°-scan range of 10-80°) was used. Infrared spectra were recorded using Bruker ATR spectrometer (scan range: 4000 to 400 cm^{-1}; resolution: 4 cm^{-1}; number of scans-24) to identify the characteristic functional groups exhibited by the samples. The melting point of all the compounds (1,2,3) and their cocrystals prepared were filled in a capillary tube and heated in a melting point apparatus (M.B. Instruments, Delhi) in the temperature range of 25 °C to 150 °C.

Results and Discussion:

In Figure 1 are shown the structures of 8-hydroxyquionoline, vanillin and succinimide respectively.

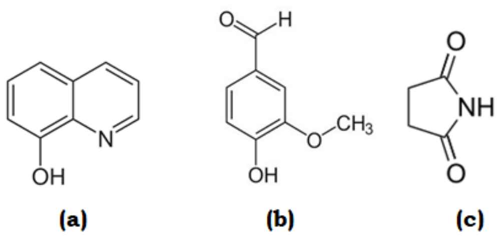

Figure 1: Molecular structure of 8-hydroxyquinoline (C_9H_7NO), Vanillin ($C_8H_8O_3$) and succinimide ($C_4H_5NO_2$)

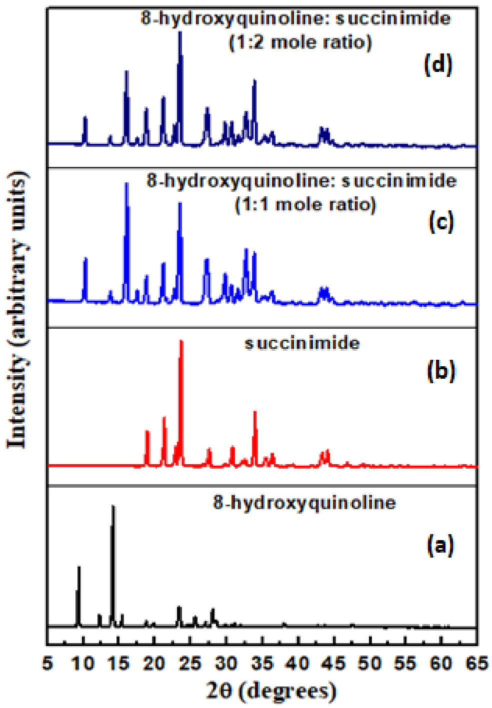

Figure 2: Powder X-ray diffraction patterns of compound 1 [8-hydroxyquinoline (8-HQ)], Compound 2 [succiminide (Succi)] and cocrystals of compounds 1 and 2 at different mole ratios

Figure 2(a) shows the powder X-ray diffraction pattern of 8-hydroxyquinoline (compound-1). The reflections were observed at 2θ = 9.37°, 12.28°, 14.16°, 15.42°, 18.76° and has been indexed to orthorhombic crystal system with cell parameters a=28.778 Å, b=25.086 Å, c=3.860 Å and α=β=γ=90°, and cell volume = 677.3 $Å^3$, ρ = 1.384 g cm^{-3}. Figure 2(b) shows the powder X-ray diffraction of compound 2 (succinimide). The reflections were observed at 2θ = 16.59°, 18.57°, 20.49°, 29.12°. The sample is be indexed to orthorhombic crystal system with space group of Pbca. The cell parameters a=7.50 Å, b=9.62 Å, c=12.75 Å, α=β=76.30°γ=90° and cell volume = 919.91 $Å^3$.

PXRD patterns of cocrystals of compounds 1 and 2 (8-hydroxy quinoline-succinimide) prepared by LAG method in different mole ratio are shown in Figure 2. The cocrystal should display a new powder diffraction pattern that is different from the individual components, often with new peaks or shifts in peak positions or shifts in the position of existing peaks should be observed due to the changes in the crystal lattice, often due to interactions between 8-HQ and the coformer (succinimide). The peaks of both the parent compounds 1 (8-HQ) and 2 (Succi) were present in the diffraction patterns of cocrystals of compounds 1 and 2 (8-HQ) and 2 (Succi) obtained in different mole ratios (see Figure 2).

8-hydroxyquinoline (8-HQ) is an aromatic compound with a hydroxyl group (-OH) attached to the quinoline ring and its infrared spectrum features the following characteristic absorption bands and are given in Table 2.

The presence of functional group was investigated using infrared spectroscopy. Infrared spectrum of compound 1 (8-hydroxyquinoline) is shown in Figure 3(a) and the interpretation of the spectral data of compound 1 (8-hydroxy quinoline) is given in table 6 and confirms with the expected peak positions (compare Tables 2 and 3).

Succinimide possess C=O and N-H groups attached to the molecule and in Table 4 is given the expected peaks at different wave numbers by the functional groups present in the succinimide molecule.

Table 2: Infrared spectral data of 8-hydroxyquinoline (expected)

Functional group	Stretch/bend	Wave number (cm^{-1})	Description
O-H	**Stretch**	3200-3600	A broad, strong peak in this region corresponds to the O-H stretching vibration of the hydroxyl group. This peak is often broad due to hydrogen bonding.

Aromatic C-H	**Stretch**	3000-3100	Sharp peaks in this region are due to the stretching vibrations of C-H bonds in the aromatic ring.
Aromatic C=C	**Stretch**	1500-1600	Peaks in this region correspond to the stretching vibrations of C=C bonds in the aromatic ring. These peaks are usually strong and well-defined.
Aromatic C-H	**Bending (Out-of-Plane)**	675-900	These peaks are associated with out-of-plane bending vibrations of C-H bonds in the aromatic ring.
C-N	**Stretch**	1200-1400	Peaks in this region can be attributed to the stretching vibration of the C-N bond in the quinoline ring.
N-H	**Bending**	1500-1650	Peaks in this region correspond to the bending vibrations of N-H bonds, if present

Table 3: Peak positions of 8-hydroxyquinoline and their characteristics in infrared spectrum

Peak positions (cm^{-1})	Assignment
3129	O-H stretching vibration
3043	C-H aromatic stretching vibration
1577	C=C stretching vibration
1498	C=N stretching vibration

Table 4: Infrared spectral data of succinimide (expected)

Functional group	Stretch/ bend	Wave number (cm^{-1})	Description
Carbonyl (C=O)	**Stretch**	1700-1760	A strong, sharp peak in this range indicates the presence of the carbonyl group in the imide structure of succinimide.
C-N	**Stretch**	1200-1400	Peaks in this range correspond to the stretching vibrations of the C-N bond in the imide ring.

N-H	**Stretch**	3200-3400	Peaks in this region indicate the stretching vibrations of N-H bonds. This peak may appear as a broad band if there is hydrogen bonding.
C-H	**Stretch**	2800-3000	Peaks in this range are associated with the stretching vibrations of C-H bonds in the aliphatic part of the molecule.
C-H	**Bending (Out-of-Plane)**	700-900	Peaks in this region correspond to out-of-plane bending vibrations of C-H bonds.

Infrared spectrum of compound 2 (succinimide) is shown in Figure 3(b) and the interpretation of the spectral data of compound 2 (succinimide) is given in table 5.

Table 5: Peak positions of succinimide and their characteristics in infrared spectrum

Peak positions (cm^{-1})	**Assignment**
3158	N-H stretching vibration
2799	C-H stretching vinration
1679	C=O stretching vibration
1357	C-H bending vibration
1179	C-N stretching vibration

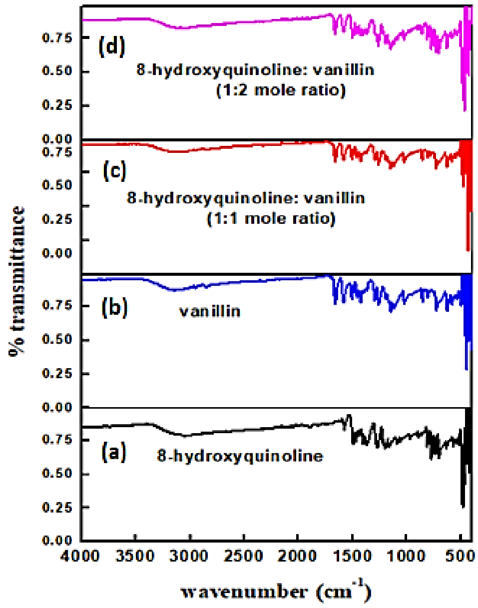

Figure 3: Infrared spectra of compound 1 [8-hydroxyquinoline (8-HQ)], Compound 2 [succiminide (Succi)] and cocrystals of compounds 1 and 2 at different mole ratios

In table 5 is given the absorption peak positions exhibited by the succinimide and its interpretation in the infrared spectral data. The experimental data given in Table 5 matches with the theoretical values (see Table 4).

Infrared spectra of cocrystals of compounds 1 and 2 at different mole ratios by LSG method are shown in Figure 3. The peak positions and their assigment for the cocrystals of compounds 1 (8-HQ) and 2 (Succ) in different mole ratios are given in Table 6.

Table 6: Infrared spectral data of cocrystals of compounds 1 and 2 at different mole ratios and their analyses

8-HQ-Succ (1:1)		8-HQ-Succ (1:2)	
Peak positions (cm^{-1})	**Assignment**	**Peak positions (cm^{-1})**	**Assignment**
3140.60	O-H stretching vibration	3140.60	O-H stretching vibration
1681.29	C=O stretching vibration	1681.29	C=O stretching vibration
1579.84	C=C stretching vibration	1579.84	C=C stretching vibration
1494.00	C=N stretching vibration	1494.00	C=N stretching vibration
1181.85	C-N stretching vibration	1181.85	C-N stretching vibration

There were no significant shifts observed in bands of IR spectra of cocrystals of compound 1 and 2 in different mole ratio (1:1, 1:2).

To verify whether the cocrystals are physical mixtures or eutectic mixture, melting point of the cocrystals of compound 1 (8-HQ) and compound 2 (Succ) in different mole ratios were recorded. In Table 7 the melting points of the precursors and their cocrystals values are reported. Physical mixtures were also prepared by taking compounds 1 and 2 in different mole ratios and ground thoroughly in a mortor and pestle without any solvent addition. The melting points of the physical mixtures of compound 1 (8-HQ) and compound 2 (Succ) in different mole ratios are also given in Table 7 which clearly demonstrates two different melting points. The results from the melting point data given in Table 7 indicates that the cocrystals of compounds 1 and 2 (in mole ratios 1:1 and 1:2) have intermediate values compared to their parent compounds and physical mixtures indeed indicating that the cocrystals are eutectic mixtures rather than mere physical mixtures of two compounds.

Table 7. Melting points of 8-HQ, Succ, and their cocrystals in different mole ratios (LAG method) and also their physical mixtures

Compounds	Melting point (°C)		
		LAG method	Physical mixture
8-HQ	72-73	-	-
Succi	125-126	-	-
8-HQ-Succi (1:1)	-	105	90-95; 114-116
8-HQ-Succi (1:2)	-	108-110	95-100; 110-115

Figure 4(b) shows the powder X-ray diffraction of compound 3 (vanillin). The reflections were observed at 2θ = 16.59°, 18.57°, 20.49°, 29.12°. The samples can be indexed to monoclinic system with space group of P21. The cell parameters a=14.04Å, b=7.87Å, c=15.03Å, α=90°, β=115.43°, γ=90° and cell volume v = 1490.3 $Å^3$.

In Figures 4(c,d) are shown the powder X-ray diffraction patterns of cocrystals of compounds 1 (8-HQ) and 3 (Van) at different mole ratio using LAG method. The peak positions of both 8-hydroxyquinoline and succinimide observed in the diffraction pattern appear in the cocrystals of compounds 1 and 3 prepared in different mole ratios indicating that it could be physical mixture or eutectic mixture.

In Table 8 the expected peak positions and their analysis for the different types of functional groups present in vanillin is given.

Table 8: Infrared spectral data of vanillin (expected)

Functional group	Stretch/bend	Wave number (cm^{-1})	Description
O-H	**Stretch**	3200-3600	A broad peak in this range indicates the presence of the hydroxyl group (–OH) in the vanillin molecule. This peak can be broad and strong due to hydrogen bonding.
Aromatic C-H	**Stretch**	3000-3100	Sharp peaks in this region are attributed to the stretching vibrations of C-H bonds in the aromatic ring of vanillin.

Aromatic C=C	**Stretch**	1500-1600	Peaks in this range correspond to the stretching vibrations of the C=C bonds within the aromatic ring.
Aldehyde C=O	**Stretch**	1700-1750	A strong, sharp peak in this region indicates the presence of the aldehyde group (–CHO) in vanillin.
Aromatic C-O	**Stretch**	1200-1300	Peaks in this region are associated with the C-O stretching vibrations in the methoxy group (–OCH_3) and the aromatic ether linkage.
C-H	**Bending (Out-of-Plane)**	675-900 cm^{-1}	Peaks in this range correspond to the out-of-plane bending vibrations of the C-H bonds in the aromatic ring.

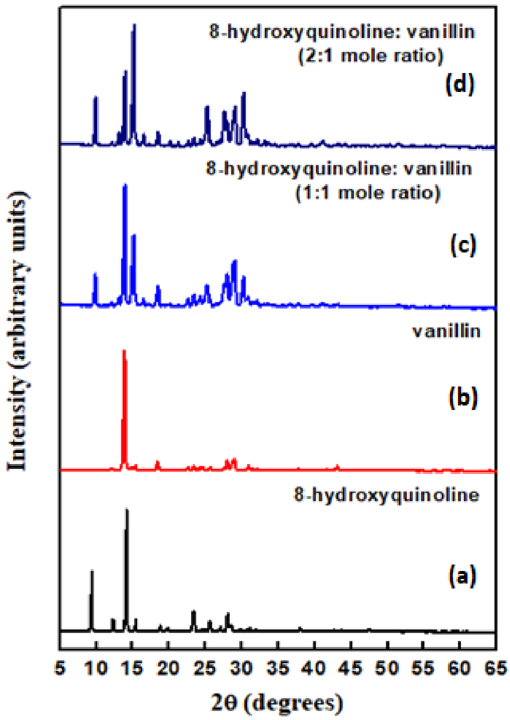

Figure 4. Powder X-ray diffraction patterns of compound 1 [8-hydroxyquinoline (8-HQ)], Compound 3 [vanillin (Van)], and cocrystals of compounds 1 and 2 at different mole ratios

Infrared spectrum of compound 3 (vanillin) is shown in Figure 4(b) and its analysis is given in table 9.

Table 9: Peak positions of vanillin and their characteristics in infrared spectrum

Peak positions (cm^{-1})	Assignment
3175	Broad O-H stretching vibration
2961	-CH stretching vibration
1662	Stretching vibration of aldehyde
1427	Stretching vibration of C=C-C
1025	Stretching vibration of O-CH_3

The peak positions exhibited by the vanillin matches with the theoretically predicted bands in the infrared spectrum of vanillin (compare Tables 9 and 10).

Infrared spectra of cocrystals of compounds 1 and 3 at different mole ratios obtained by LSG method are shown in Figure 5 along with compound 1 and compound 3 for comparison. The peak positions and their assigment for the cocrystals of compounds 1 (8-HQ) and 3 (Van) in different mole ratios are given in Table 10.

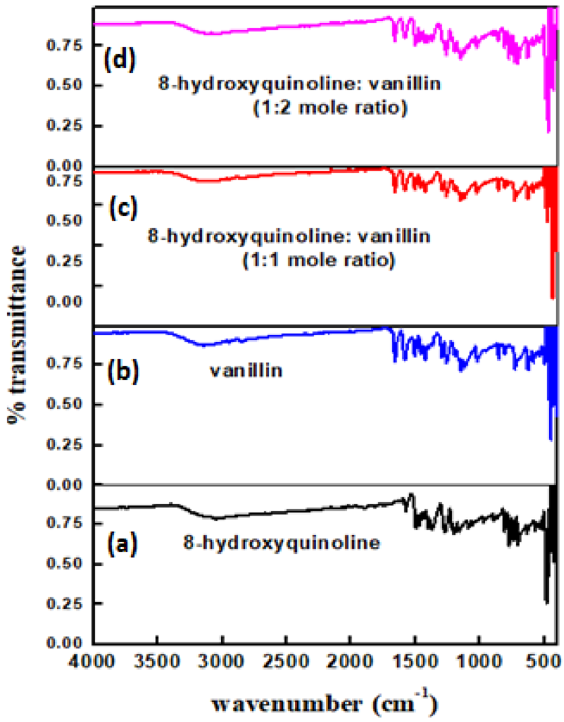

Figure 5. Infrared spectra of compound 1 [8-hydroxyquinoline (8-HQ)], Compound 3 [Vanillin (Van)], and cocrystals of compounds 1 and 3 at different mole ratios

Table 10: Infrared spectral data of cocrystals of compounds 1 and 3 at different mole ratios and their analyses

8-HQ-Van (1:1)		8-HQ-Van (2:1)	
Peak positions (cm^{-1})	**Assignment**	**Peak positions (cm^{-1})**	**Assignment**
3125	O-H stretching vibration	3125	O-H stretching vibration
1665.69	-CHO stretching vibration	1665.69	-CHO stretching vibration
1579.84	C=C stretching vibration	1579.84	C=C stretching vibration
1025.78	O-CH_3 stretching vibration	1025.78	O-CH_3 stretching vibration

Negligible variations were observed in the bands of infrared spectra of compounds 1 and 3 with their cocrystals in different mole ratio (1:1, 2:1). To verify that the cocrystals are physical mixture or eutectic mixture, melting points of compound 1, compound 3 and cocrystals of compounds 1 and 3 in different mole ratio (1:1; 2:1), physically ground mixtures of compounds 1 and 3 without solvent in different mole ratios (1:1; 2:1) were recorded and in Table 11 are given the data.

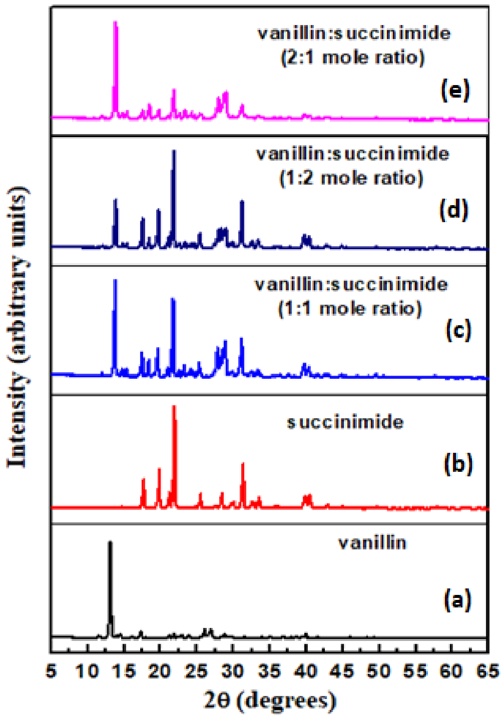

Figure 6: Powder X-ray diffraction patterns of compound 3 [Vanillin (Van)] and Compound 2 [Succinimide (Suc)], and cocrystals of compounds 3 and 2 at different mole ratios

Table 11: Melting points of 8-HQ, Van, and their cocrystals in different mole ratios (LAG method) and also their physical mixtures

Compounds	Melting point (°C)		
		LAG method	**Physical mixture**
8-HQ	72-73		
Van	82-83		
8-HQ-Van (1:1)		52-53	57
8-HQ-Van (2:1)		56	60-63

The results from the melting point data given in Table 11 indicates that the cocrystals of compounds 1 and 3 (in mole ratios 1:1 and 2:1) have intermediate values compared to their parent compounds and physical mixtures indeed indicating that the cocrystals are eutectic mixtures rather than mere physical mixtures of two compounds.

Figure 6 shows the powder X-ray diffraction of vanillin-succiminide at different mole ratio using LAG method. The peak positions of both vanillin and succiminide are observed the diffraction patterns of cocrystals of vanillin and succinimide in different mole ratio (1:1 1:2 and 2:1) and the diffraction patterns of the compound 3 and 2 are also shown in the Figure 6 for comparison.

Infrared spectra of cocrystals of compound 3 and 2 by LSG method are shown in Figure 7. Infrared spectral data of cocrystals of compound 3 and 2 in different mole ratio (1:1, 1:2, 2:1) are given in table 12. No significant shifts have been observed in bands of infrared spectra of cocrystals containing compound 3 and 2 at different mole ratio (1:1, 1:2, 2:1).

To verify that the cocrystals are physical mixture or eutectic mixture, melting points of compound 1, compound 3 and cocrystals of compounds 1 and 3 in different mole ratio (1:1; 2:1), physically ground mixtures of compounds 1 and 3 without solvent in different mole ratios (1:1; 2:1) were recorded and in Table 13 are given the data. The results from the melting point data given in table 13 indicates that the cocrystals of compounds 1 and 3 (in mole ratios 1:1, 1:2 and 2:1) have intermediate values compared to their parent compounds and physical mixtures indeed indicating that the cocrystals are eutectic mixtures rather than mere physical mixtures of two compounds.

Table 12: Infrared spectral data of cocrystals of compound 3 and 2 and its analysis

Van-Succi (1:1)		Van-Succi (1:2)		Van-Succi (2:1)	
Peak positions (cm^{-1})	**Assignment**	**Peak positions (cm^{-1})**	**Assignment**	**Peak positions (cm^{-1})**	**Assignment**
3156.21	N-H stretching vibration	3156.21	N-H stretching vibration	3156.21	N-H stretching vibration
1665.69	-CHO stretching vibration	1665.69	-CHO stretching vibration	1665.69	-CHO stretching vibration
1174.05	C-N stretching vibration	1174.05	C-N stretching vibration	1174.05	C-N stretching vibration
1025.78	O-CH_3 stretching vibration	1025.78	O-CH_3 stretching vibration	1025.78	O-CH_3 stretching vibration

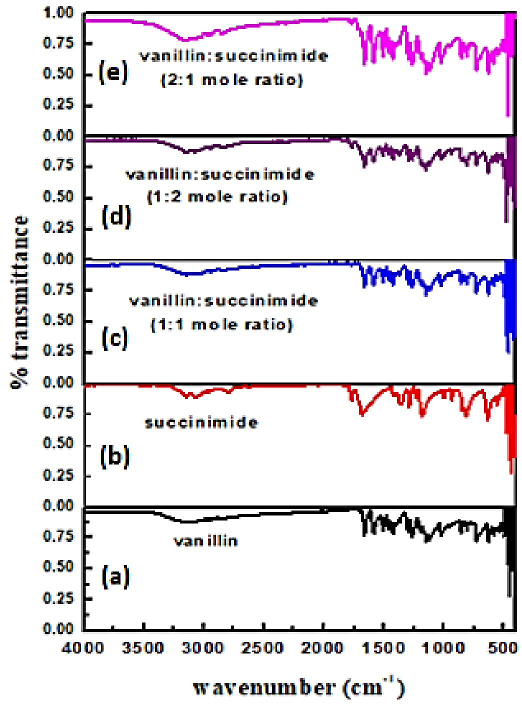

Figure 7. Infrared spectra of compound 3 [Vanillin (Van)] and Compound 2 [Succinimide (Suc)] and cocrystals of compounds 3 and 2 at different mole ratios

Table 13: Melting points of Van, Succi, their cocrystals in different mole ratios (LAG method) and also their physical mixtures

Compounds	**Melting point (°C)**		
		LAG method	Physical mixture
Van	82-83		
Succi	125-126		
Van-Succi (1:1)		65	78-80
Van-Succi (1:2)		85-87	68-70 90-92
Van-Succi (2:1)		65-68	67-68

The 8-HQ, Van and cocrystals of 8-HQ-Van (1:1, 2:1) were exposed to different wavelength of light, they exhibit slight variation in their color indicating that it may have interesting optical properties.

Conclusion:

8-hydroxyquinoline (8-HQ), succinimide (Succi) and vanillin (Van) are extensively used as APIs/conformers in cocrystal engineering to enhance the physicochemical properties of a wide range of compounds. Their ability to form strong hydrogen bonds, along with its aromatic nature, makes it suitable for pairing with various coformers, resulting in cocrystals with improved solubility, stability, and potential applications in pharmaceuticals, flavors, nutraceuticals. Cocrystals of 8-HQ-Succi, 8-HQ-Van and Van-Succi in different mole ratios have been prepared by liquid assisted grinding methods. Powder X-ray diffraction data of cocrystals of 8-HQ-Succi, 8-HQ-Van and Van-Succi exhibit peaks of starting compounds. Also in infrared spectra, no significant changes in the band positions were observed in cocrystals of 8-HQ-Succi, 8-HQ-Van and Van-Succi compared to their starting compounds. Melting point data of cocrystals of 8-HQ-Succi, 8-HQ-Van and Van-Succi exhibit differences in contrast to the melting points of the starting compounds as well as physical mixtures indicating that the cocrystals are forming eutectic mixture. The eutectic mixtures obtained by the above methods can have improved solubility and also be explored for organic device based applications.

Acknowledgements:

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NEOTERIC METHOD FOR THE SHORTEST PATHS

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Abstract:

Traveling to various destinations is an integral part of our l ives, whether for daily activities or leisure. Finding the most efficient way to navigate between locations can be challenging. While testing all possible routes is one option, employing mathematical and computational methods to determine the shortest path offers a more effective solution. This paper explores the construction of shortest paths and introduces a novel algorithm designed to minimize the total cost of travel, which may include distance, time, or other relevant factors. We also apply our method to real-world scenarios, demonstrating its potential to save time and enhance overall travel efficiency.

Introduction:

Network analysis is a system which plans the projects by analyzing the project activities. Projects are broken down into individual tasks or activities, which are arranged in logical sequence. It is also decided that which tasks will be performed simultaneously and which other sequentially. A network diagram is prepared, which presents visually the relationship between all the activities involved and the cost for different activities. Network analysis helps designing, planning, coordinating, controlling and in decision-making in order to accomplish the project economically in the minimum available time with the limited available resources. The network analysis fulfils the objectives of reducing total time, cost, idle resources, interruptions and conflicts.

Review of Literature:

Shortest path algorithms have garnered significant attention across various fields, particularly in transportation networks. Orda and Rom (1990) explored shortest-path and minimum-delay algorithms in networks with time-dependent edge lengths, emphasizing the importance of considering time factors in routing. Benjamin and Zhan (1997) introduced rapid shortest path algorithms optimized for real road networks, highlighting efficient data structures and procedures. Chen *et al.* (2007) enhanced Dijkstra's algorithm by utilizing priority queues, improving its performance for complex routing tasks. Gass and Fu (2013) provided an overview of Dijkstra's algorithm in the "Encyclopedia of Operations Research and Management Science," emphasizing its foundational significance in operations research. Paneer Selvam (2013) discussed network techniques and transportation problems in his comprehensive view of operational research, showcasing the breadth of shortest path applications. Grandinetti *et al.* (2014) investigated the multi-objective multi-vehicle pickup and delivery problem with time windows, demonstrating the algorithm's relevance in intricate transportation scenarios. Chen *et al.* (2014) applied Dijkstra's algorithm to optimize evacuation paths for vehicles, underlining its critical role in emergency management. Wang (2012) proposed improvements to Dijkstra's algorithm for practical applications, focusing on enhancing its efficiency in real-world contexts. Xu *et al.* (2007) optimized Dijkstra's algorithm for sparse networks, contributing to its adaptability in different data environments. Liu and Lee (2018) developed a shortest path algorithm specifically for the autonomous vehicle delivery problem, illustrating the algorithm's relevance in modern transportation technology. Garg (2018) presented a dynamic approach to the shortest path problem by retroactively adjusting priorities in Dijkstra's algorithm, addressing challenges in dynamic environments. He *et al.* (2022) introduced dynamic discretization discovery algorithms for time-dependent shortest path problems, expanding the methodologies available for temporal complexities in path finding. This literature highlights the ongoing evolution and practical significance of shortest path algorithms across a wide range of applications.

Algorithm For Finding Shortest Path

Consider the arcs of the distance network of the given problem. The arcs is the network is directed and each are represented as (i, j) with i< j. The steps of the algorithm are summarized below:

Step 1: Arrange the arcs along with their distances as per ascending order of their distances

Let this arrangement be called as set M.

Step 2: Mark all the smallest paths in the graph by the following steps.

Step 3: Find the path that connects with the initial node and corresponding nodes.

CASE (i): If there are two minimum path that ejects from the starting path, then, choose the least minimum path and delete the other one.

CASE (ii): If there are two paths having same distance as minimum, that ejects from the starting path, then choose the minimum of sum of the corresponding path and succeeding path at that it occurs and delete the other one from the set M.

Step 4: Delete the path that remains uncertain

Step 5: Proceed the steps 2 & 3 until the destination is arrived.

Step 6: Finally, Consider the reduced paths that occur from Step 1 to Step 3.

CASE (i): If one path occur, it make it as an optimal route.

CASE (ii): If more than one path occur then, choose the minimum distance of the path and make it as an optimum route.

Example

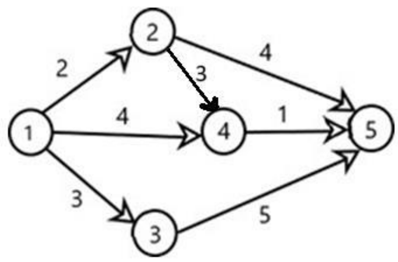


Figure (a)

Step 1: Arrange the arcs along with their distances as per ascending order of their distances.

Arcs	Distance
1-2	2
1-3	3
2-4	3
2-5	4
3-5	5
4-5	1

The arranged distance in ascending order are as follows

Arcs	Distance
4-5	1
1-2	2
1-3	3
2-4	3
2-5	4
3-5	5

Step 2: Using the above table mark all the smallest paths in the graph by step by step.

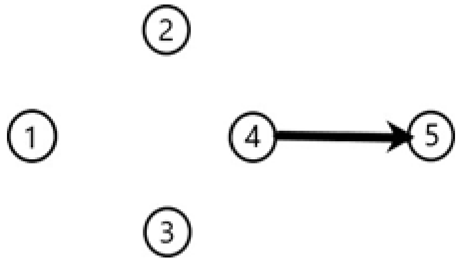


Figure (b)

Step 3: After completing all the step we get the following shortest path graph figure(c)

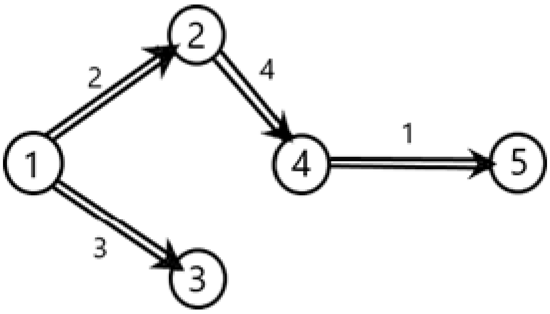


Figure (c)

3.1 Application of Neoteric Method on Real Life Problem

Shortest paths are important when traveling from one place to another. They have numerous applications in many types of networks and can help solve a variety of real-world problems. Every day, we make decisions about which routes we use to travel between different places. In your home, you may travel from your bedroom to your kitchen. Outside your home, you may travel from your home to school. Suppose that we have a network of places that are connected to each other by streets and walkways.

3.1.1 Shortest Paths

In mathematics, the study of paths often involves finding the shortest route between two nodes. A shortest path is defined as the route that has the fewest edges when all edges have the same cost, such as equal-length streets. More generally, for a given origin and destination node, a shortest path is one that minimizes the total cost, which can encompass distance, time, or other metrics. Recognizing this significance, we applied our proposed algorithm to determine the shortest route from Pondicherry Bus Stand to Villianur, effectively calculating the optimal path based on these criteria.

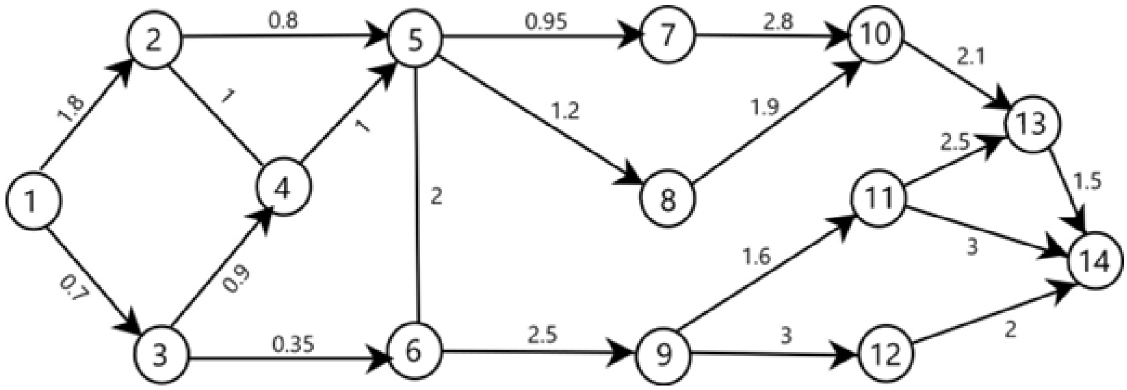


Figure 3.1.2

Consider nodes as places and paths as kilometres that reaches the destination. The nodes can be represented as,

1 → Bus Stand

2 → Mudaliarpet

3 → Nellithope

4 → Anitha Nagar

5 → Marapalam

6 → Indira Gandhi Square

7 → Murungapakkam

8 → Velrampet Lake

9 → Moolakulam

10 → Kombakkam

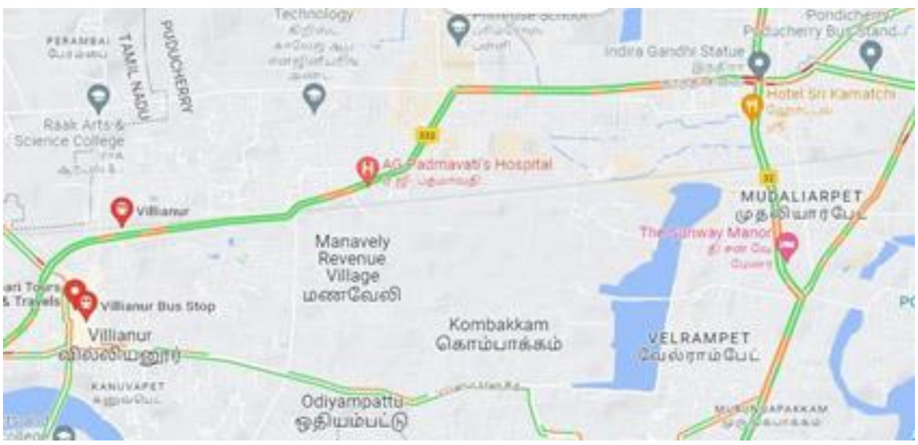
11 → Arumparthapuram

12 → Perambai

13 → Odiampet

14 → Villianur

The Real road map from Puducherry bus stand to villianur



There are 3 Main routes from Bus stand to the Villianur. The directed arcs represent to and fro way.

- ✓ The First route starts with the node New bus stand(1) and then it goes to the node Nellithope (3) and then to Indira Gandhi Square(6) and the Moolakulam (9) then to the Arumparthapuram (11) and then to reach our destination villianur (14).
- ✓ The Second route starts from New bus stand (1) to the Mudaliarpet (2) then to the Murugapakkam (7) then move towards Kombakkam (10) then to the Odiampet (13) and then it reaches the Villianur (14).
- ✓ The Third route starts with the New bus stand (1) and then to the Nellithope(3) then to the Anithanagar (4) and then Marapallam (5) and to the Velrampet Lake (8) and now joining the Kombakkam(10) and reaches the Villianur (14) through the route odiampet (13).Now, applying our algorithm to this real applications by taking the arcs and distance .

Arrange the arcs along with their distances as per ascending order of their distances Let this arrangement be called as set M.

Table 1

ARCS	1-2	1-3	2-4	2-5	3-4	3-6	4-5	5-6	5-7	5-8
DISTANCE	1.8	0.7	1	0.8	0.9	0.35	1	2	0.95	1.2

ARCS	6-9	7-10	8-10	9-11	9-12	10-13	11-13	11-14	12-14	13-14
DISTANCE	2.5	2.8	1.9	1.6	3	2.1	2.5	3	2	1.5

Using the above table mark all the smallest paths in the graph by the following steps.

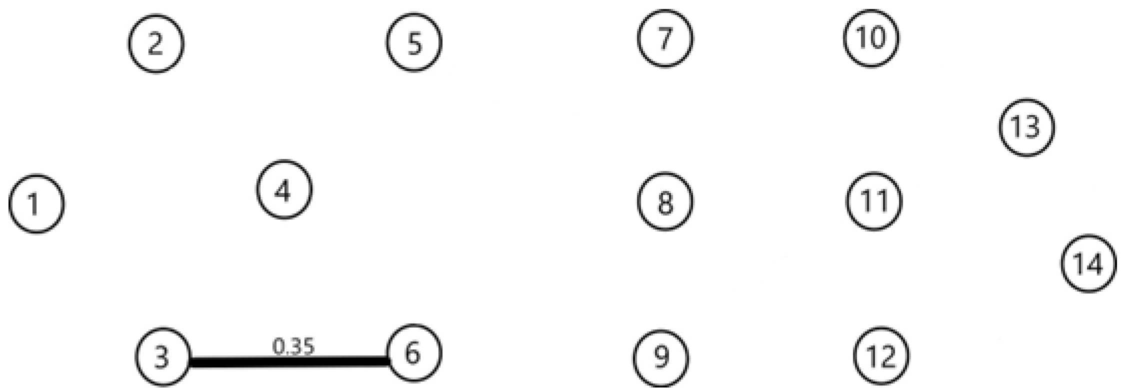


Figure 3.1.3

Find the path that connects with the initial node(1) and corresponding nodes(2) and (3). Here, comparing all distances node 3-6 is the smallest distance so we first mark that arc as bold.

Table 2

ARCS	1-2	1-3	2-4	2-5	3-4	4-5	5-6	5-7	5-8	6-9
DISTANCE	1.8	0.7	1	0.8	0.9	1	2	0.95	1.2	2.5

ARCS	7-10	8-10	9-11	9-12	10-13	11-13	11-14	12-14	13-14
DISTANCE	2.8	1.9	1.6	3	2.1	2.5	3	2	1.5

Now, removing next least distance arc from table that will be node 1-3.

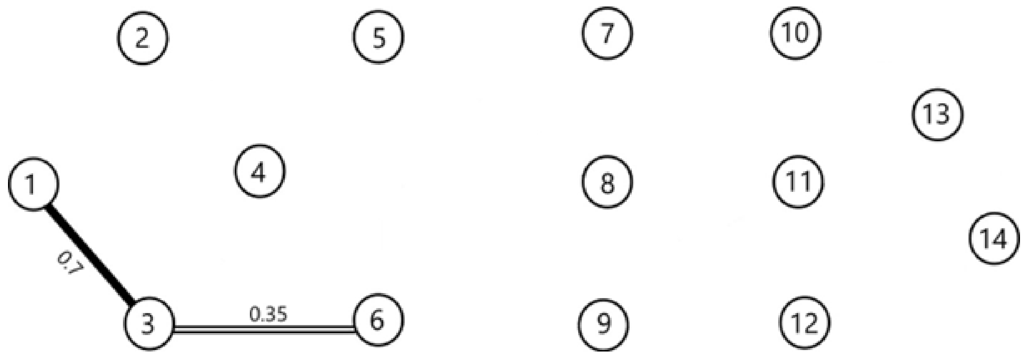


Figure 3.1.4

Mark the arc as bold in the above directed graph.

Table 3

ARCS	1-2	2-4	2-5	3-4	4-5	5-6	5-7	5-8	6-9	7-10
DISTANCE	1.8	1	0.8	0.9	1	2	0.95	1.2	2.5	2.8

ARCS	8-10	9-11	9-12	10-13	11-13	11-14	12-14	13-14
DISTANCE	1.9	1.6	3	2.1	2.5	3	2	1.5

Continuing this way next least distance arc 2-5 will be removed from the table.

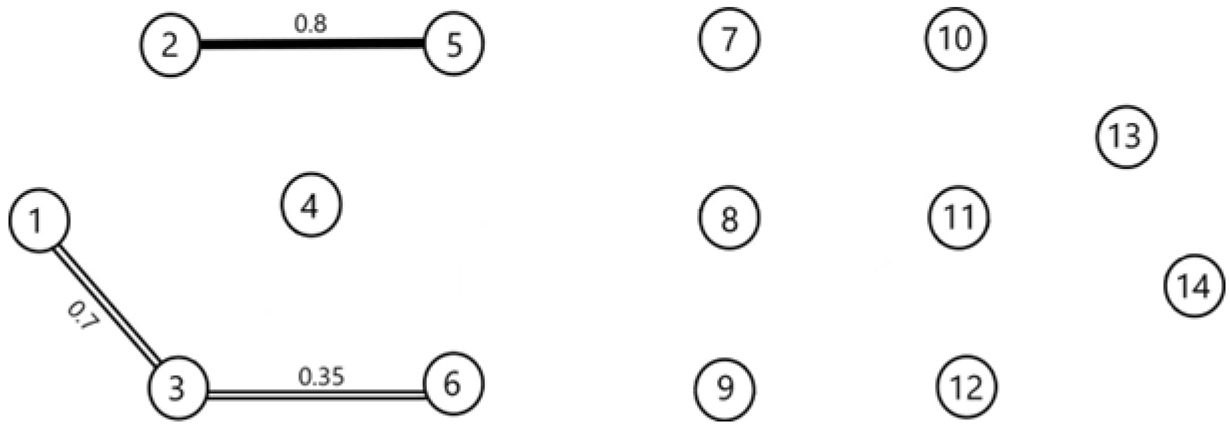


Figure 3.1.5

The deleted arc will be marked bold in the above figure 3.1.5.

Table 4

ARCS	1-2	2-4	3-4	4-5	5-6	5-7	5-8	6-9	7-10	8-10
DISTANCE	1.8	1	0.9	1	2	0.95	1.2	2.5	2.8	1.9

ARCS	9-11	9-12	10-13	11-13	11-14	12-14	13-14
DISTANCE	1.6	3	2.1	2.5	3	2	1.5

Finding the next least distance and delete the arc from the table.

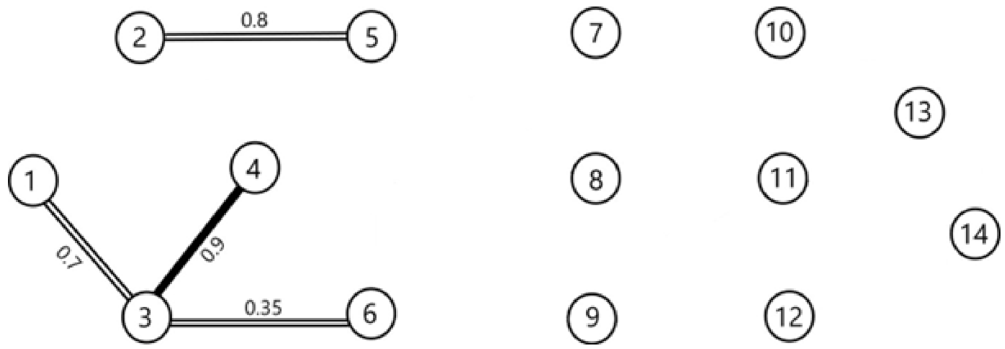


Figure 3.1.6

Table 5

Figure 3.1.6ARCS	1-2	2-4	4-5	5-6	5-7	5-8	6-9	7-10	8-10	9-11
DISTANCE	1.8	1	1	2	0.95	1.2	2.5	2.8	1.9	1.6

ARCS	9-12	10-13	11-13	11-14	12-14	13-14
DISTANCE	3	2.1	2.5	3	2	1.5

Proceed until we get the required shortest route.

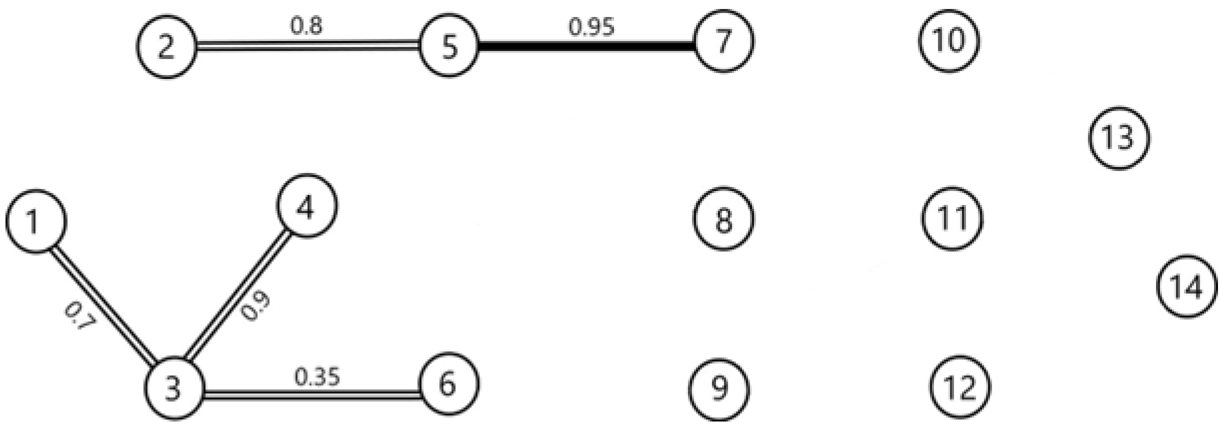


Figure 3.1.7

Table 6

ARCS	1-2	2-4	4-5	5-6	5-8	6-9	7-10	8-10	9-11	9-12
DISTANCE	1.8	1	1	2	1.2	2.5	2.8	1.9	1.6	3

ARCS	10-13	11-13	11-14	12-14	13-14
DISTANCE	2.1	2.5	3	2	1.5

Now, we got different arcs with same distance here we have choose the minimum of sum of the corresponding path and succeeding path at that it occurs and delete the other one from the set M.

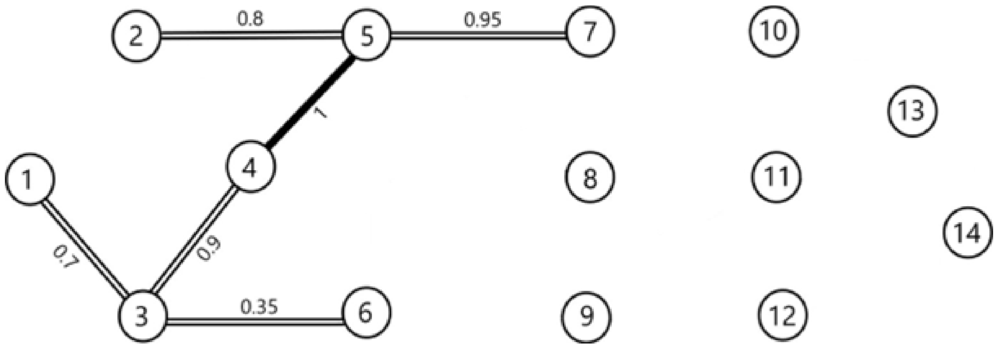


Figure 3.1.8

In comparison with the arcs 2-4 and 4-5 we choose 4-5 as the minimum sum of the sum of the corresponding path and succeeding path.

Table 7

ARCS	1-2	5-6	5-8	6-9	7-10	8-10	9-11	9-12	10-13
DISTANCE	1.8	2	1.2	2.5	2.8	1.9	1.6	3	2.1

ARCS	11-13	11-14	12-14	13-14
DISTANCE	2.5	3	2	1.5

Here, next 5-8 arcs is the least in comparison with arcs we have now , so 5-8 node is to be deleted from the table 7 and should be marked in the below graph 3.1.9.

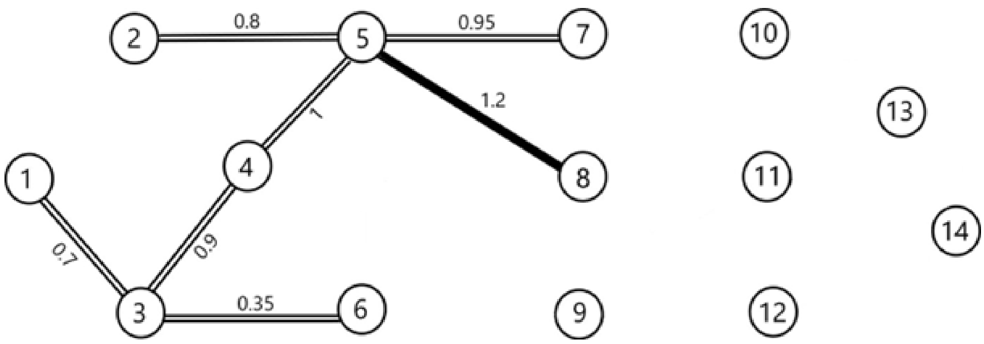


Figure 3.1.9

Table 8

ARCS	1-2	5-6	6-9	7-10	8-10	9-11	9-12	10-13	11-13
DISTANCE	1.8	2	2.5	2.8	1.9	1.6	3	2.1	2.5

ARCS	11-14	12-14	13-14
DISTANCE	3	2	1.5

By step 2 mark the next smallest path and proceed this way until we get the required destination.

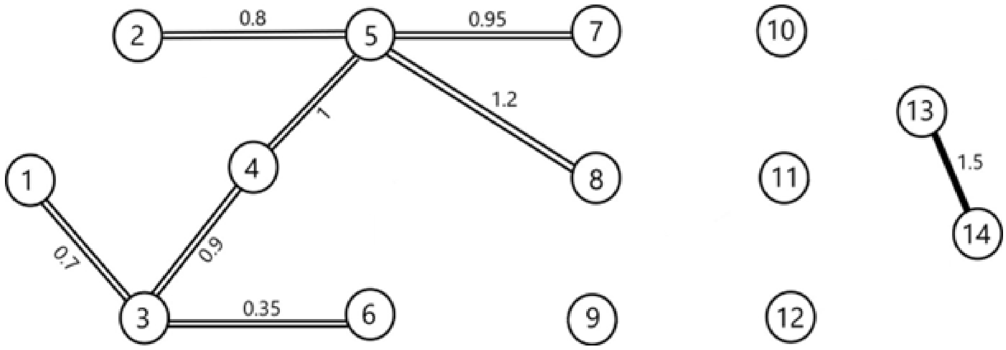


Figure 3.1.10

The next shortest distance 13-14 from the table is removed and marked bold in the above directed graph.

Table 9

ARCS	1-2	5-6	6-9	7-10	8-10	9-11	9-12	10-13	11-13	11-14
DISTANCE	1.8	2	2.5	2.8	1.9	1.6	3	2.1	2.5	3

ARCS	12-14
DISTANCE	2

In the above table 9 we would have found that 9-11 path is the smallest of all as having 1.6 km as the distance.

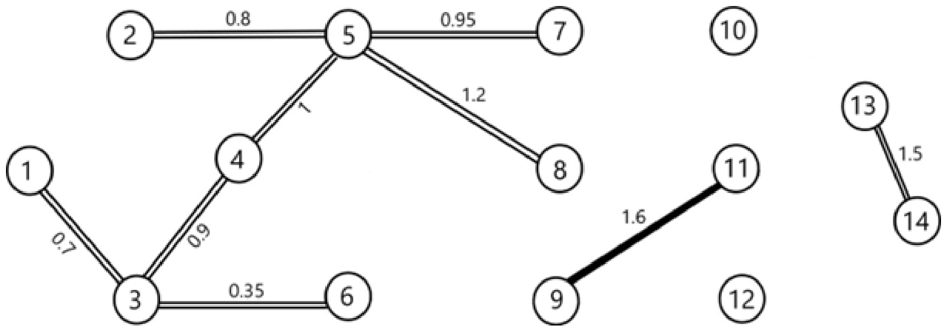


Figure 3.1.11

The deleted path 9-11 should be marked bold as in the above figure 3.1.11

Table 10

ARCS	1-2	5-6	6-9	7-10	8-10	9-12	10-13	11-13	11-14	12-14
DISTANCE	1.8	2	2.5	2.8	1.9	3	2.1	2.5	3	2

In this step we got 1-2 path as the least path but if we mark that way it would creates loops along the nodes 1,2,5,4 and 3

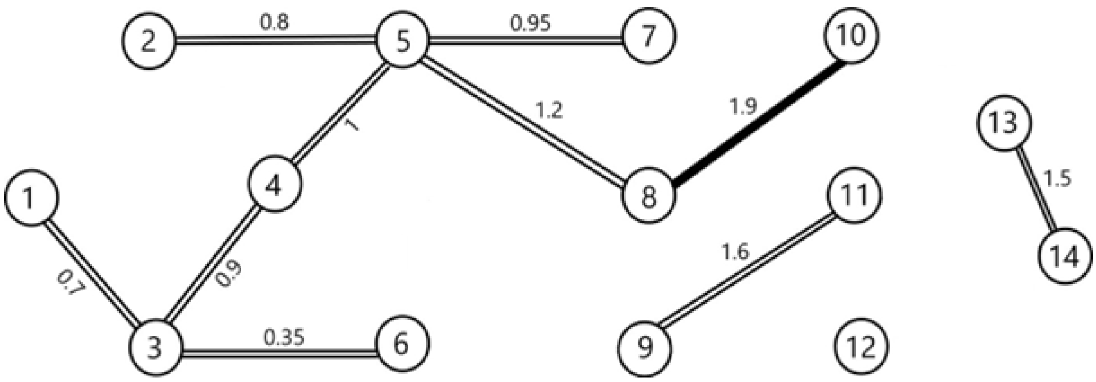


Figure 3.1.12

Removing the looping path and adding next least path 8-10.

Table 11

ARCS	5-6	6-9	7-10	9-12	10-13	11-13	11-14	12-14
DISTANCE	2	2.5	2.8	3	2.1	2.5	3	2

In table 11 we got another looping path 5-6 but though it creates loops along the paths 3, 4, 5 and 6. It should not be considered as a optimum path.

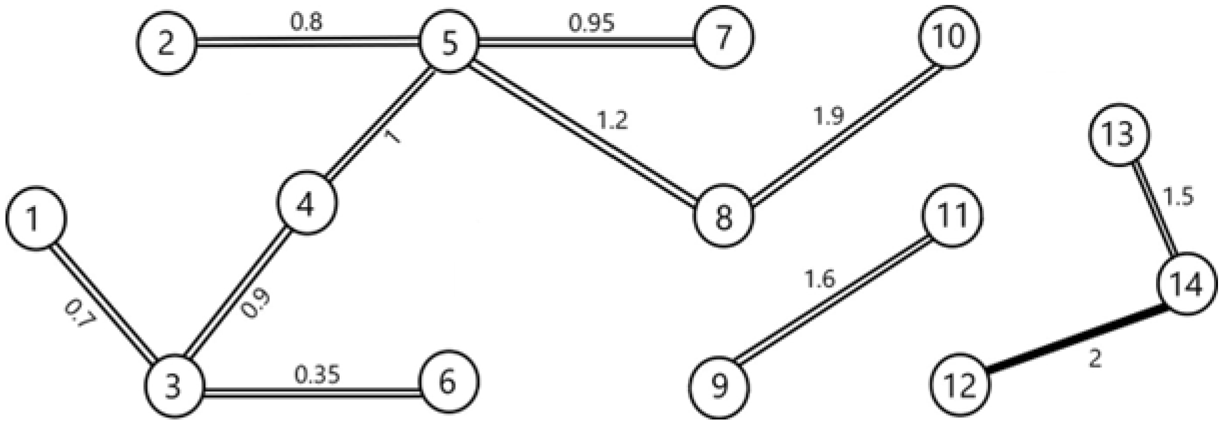


Figure 3.1.13

The next minimum distance path 12-14 is considered and removed from the above table11 by adding the path in the above figure 3.1.13.

Table 12

ARCS	6-9	7-10	9-12	10-13	11-13	11-14
DISTANCE	2.5	2.8	3	2.1	2.5	3

Using step 2 and 3 proceeding and finding the corresponding least paths.

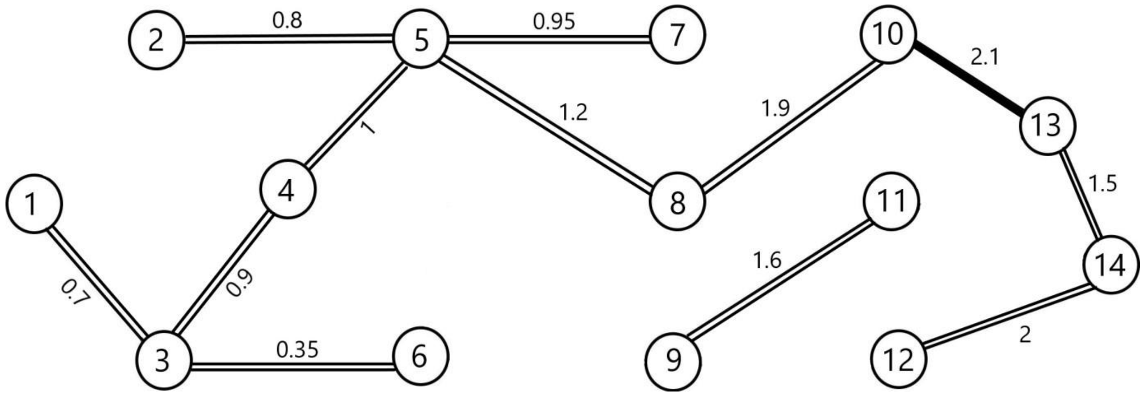


Figure 3.1.14

Now, marking 10-13 as shown in the above figure 3.1.14. as the next least distance path.

Table 13

ARCS	6-9	7-10	9-12	11-13	11-14
DISTANCE	2.5	2.8	3	2.5	3

By using the Neoteric Algorithm's step 2 and 3 proceed the further paths by removing the minimum distance 6-9 as 2.5 km and following step 15.7.

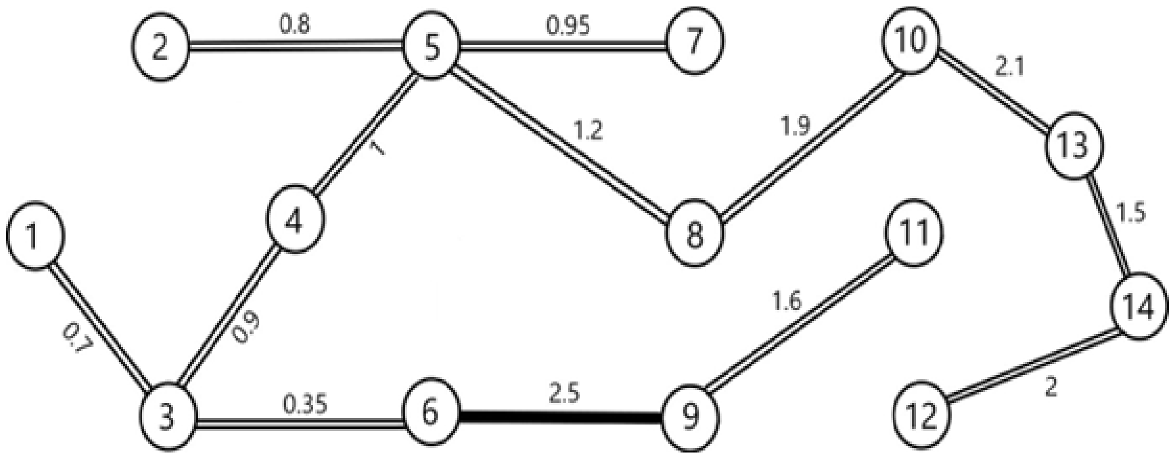


Figure 3.1.15

Mark the undeleted path in the above figure 3.1.15

Table 14

ARCS	7-10	9-12	11-13	11-14
DISTANCE	2.8	3	2.5	3

Here, we found more than one least paths 7-10, 9-12 and 11-13 which creates loops along many nodes, so we could consider as these nodes as looping nodes and deleting from the table and graph.

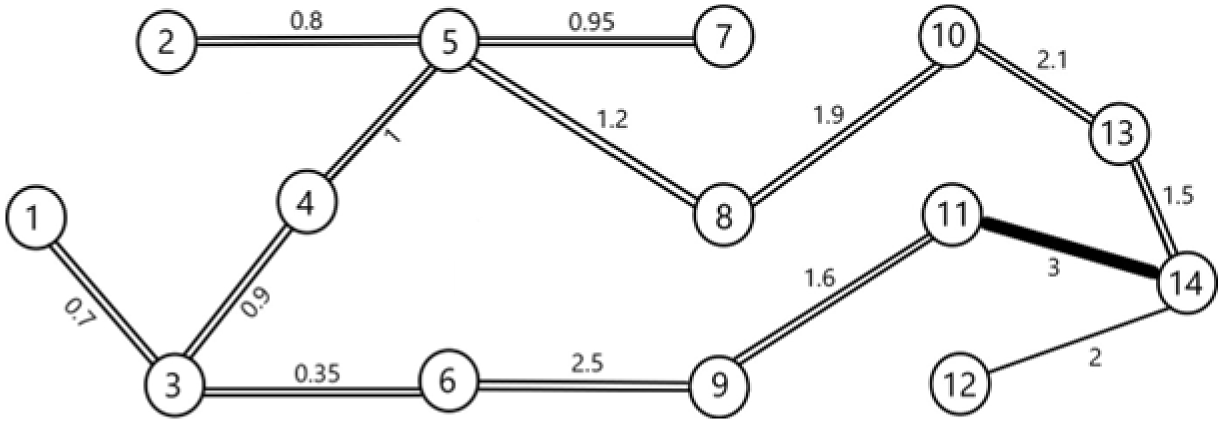


Figure 3.1.16

By Neoteric Algorithm's Step 2 delete the paths that remains uncertain and disconnected to the preceding path or the corresponding path. The uncertain arcs (paths) are 2-5, 5-7 and 12-14.

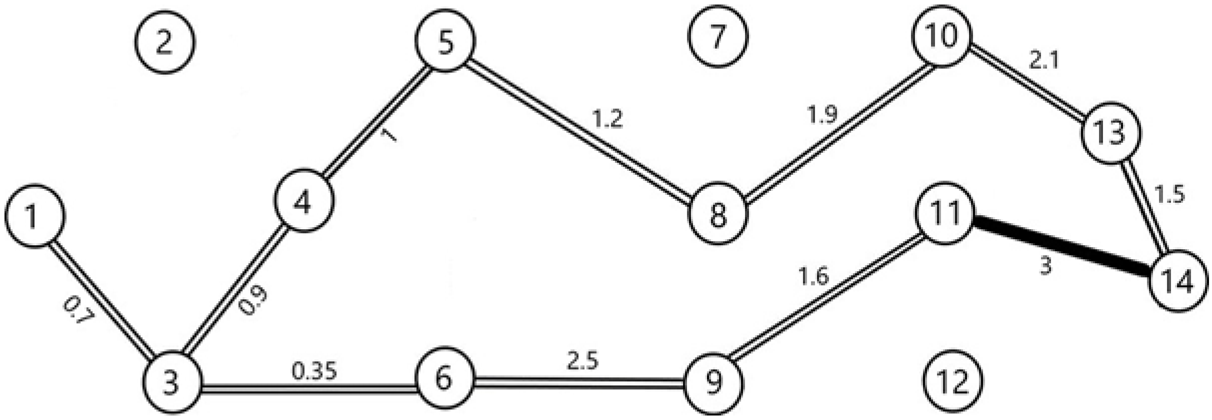


Figure 3.1.17

After removing all uncertain paths that are standing alone, finally we got two paths to reach our destination. By Neoteric Algorithm if more than one path occur then, we should choose the minimum distance of the path and make it as a optimum route. Here, the optimum route is 1-3-6-9-11-14 is required shortest distance path. Now, applying Dijkstra's Algorithm that to real life situation we have crossed, Based on guidelines of this step, the Shortest Path is 1-3-6-9-11-14 .While comparing with the Dijkstra's algorithm, our algorithm also gives the same shortest route effectively and in short span of time.

Conclusion and Findings of the Study:

The primary drawback of traditional shortest path algorithms is their reliance on blind searches, which can lead to significant time inefficiencies and resource waste. In contrast, our proposed method optimizes route selection by prioritizing paths that originate from the minimum distance, resulting in faster execution times. While other algorithms tend to favor shorter burst times for quicker execution, our approach effectively handles longer routes with comparable speed. This enhancement not only streamlines the shortest path determination process but also maximizes resource efficiency, making it a valuable alternative in transportation analytics.

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EMERGING INNOVATIVE APPROACHES IN SCIENCE RESEARCH

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Introduction:

Addressing difficult global issues and advancing society depend heavily on scientific and technological innovation. This essay examines several cutting-edge strategies that have been created and put into practice recently to improve the process of technology development and scientific discovery. Through an analysis of these methods, we hope to offer a thorough grasp of how innovation can be methodically encouraged and incorporated into many fields and sectors. Science is changing quickly thanks to creative methods that improve the calibre, velocity, and significance of research. Multidisciplinary approaches, cutting-edge technologies, and innovative research procedures are expanding the boundaries of scientific discovery as scientific issues get more complicated. The most revolutionary methods in contemporary science research will be covered in this chapter, such as multidisciplinary cooperation, data science and machine learning, open science projects, and artificial intelligence integration. Technology's constant advancement has drastically changed the field of scientific study. New technologies are changing approaches, improving capacities, and opening up previously unheard-of findings in a variety of fields. In order to demonstrate how these innovations are enabling breakthroughs and tackling difficult global issues, this chapter examines the effects of artificial intelligence (AI), big data analytics, blockchain technology, the Internet of Things (IoT), and sophisticated simulation techniques on scientific research.

The development of scientific research methods can be viewed as an ongoing interaction between technological innovation and theoretical investigation. In the past, researchers collected data using basic methods and tools, such the human eye or crude apparatus. But much as technology advanced, so did researchers' capacities.

Historical Background: Research Revolutionary Tools

- Understanding the historical background of these developments is crucial to appreciating their importance. Early scientific efforts were limited by technological constraints. Although the 17th-century scientific revolution, which was marked by individuals such as Galileo and Newton, established the foundation for contemporary scientific research, it was nonetheless constrained by the instruments of the day.
- A new age of technological innovation was brought about by the Industrial Revolution of the 18th and 19th centuries, when advancements in laboratory equipment and tools like the steam engine made it possible to conduct more thorough and effective experiments. By the 20th century, the development of digital technology and electronics had started to drastically alter scientific study.
- The Human Genome Project, which was started in 1990 and finished in 2003, was a significant accomplishment in this regard. It demonstrated the ability of computational biology and contemporary sequencing technologies to map the complete human genome, an accomplishment that would have been impossible without the technological advancements of the previous decades. This effort, which involves thousands of scientists and institutions worldwide, is a prime example of how technical innovation may support collaborative research.

Interdisciplinary Research

- In order to tackle complicated issues that cannot be resolved within the boundaries of a single subject, interdisciplinary study integrates techniques and information from several fields. This strategy has gained traction recently as scientists have realised that a variety of expertise is needed to address many of today's issues, including environmental deterioration and public health emergencies. The cooperation of ecologists, urban planners, and social scientists in tackling urban sustainability is a noteworthy illustration of interdisciplinary study. Researchers have created creative methods for building sustainable cities that strike a balance between environmental health and human needs by incorporating ecological concepts into urban planning. But there are drawbacks to interdisciplinary study as well, such as communication difficulties and disparate disciplinary cultures. Establishing shared objectives, encouraging respect for one another, and applying integrative frameworks that promote cross-disciplinary understanding are frequently necessary for successful collaborations.

Artificial Intelligence and Large-scale Data Utilisation

- The field of scientific research has changed since the introduction of big data. Large volumes of data produced by numerous sources, such as social media, sensors, and satellite photography, are now available to researchers. Unprecedented chances for insights and discoveries are presented by this plethora of data. However, there are many difficulties in analysing such vast and intricate information.
- In this situation, artificial intelligence (AI) is essential because it allows researchers to glean insightful patterns and forecasts from large amounts of data. To help policymakers make well-informed decisions, artificial intelligence (AI) algorithms, for example, evaluate historical data and climate models to forecast future climate scenarios. Similar to this, AI methods are applied in genomics to examine DNA sequences, resulting in improvements in targeted medicines and personalised medicine.

The Science of Citizens

- Involving non-professionals in scientific research and enabling the general public to participate in data collection, processing, and interpretation is known as "citizen science." This creative method democratises science, involves communities, and improves the general public's comprehension of scientific methods.
- The Audubon Society's Christmas Bird Count, in which volunteers count bird numbers, and the Galaxy Zoo project, which asks the public to categorise galaxies using telescope photos, are two instances of effective citizen scientific initiatives. In addition to providing useful data for scientific research, these programs help participants develop a sense of accountability and ownership. Notwithstanding its advantages, citizen science has drawbacks, such as the need to ensure data quality, handle participant motives, and provide sufficient training. While tackling these obstacles, researchers can optimise the potential of citizen science by instituting unambiguous procedures, offering instructional materials, and cultivating a cooperative atmosphere.

Collaboration and Open Science

- A developing paradigm in research that encourages openness, accessibility, and cooperation is called "open science." The goal of open science is to promote innovation and speed up the distribution of information by making research findings, data, and methodology openly available.

- The emergence of social media and internet platforms has made it easier for researchers worldwide to collaborate. Researchers may work together across geographic boundaries, share their findings, and get comments thanks to programs like the Open Science Framework and preprint servers. These platforms also help to increase the visibility of under-represented voices in science and decrease publication delays.
- However, issues with data privacy, intellectual property rights, and the conventional academic publishing model present difficulties for the open scientific movement. A change in academic culture that encourages a more open and cooperative approach to research is necessary to address these issues.

Innovative Techniques and Technologies

- Research methods in several areas have changed because of the quick development of technologies. New areas of scientific investigation have been made possible by innovations like remote sensing, nanotechnology.
- For instance, Clustered regularly interspaced short palindromic repeats (CRISPR) technology revolutionises industries like genetics and biotechnology by enabling researchers to modify genomes with previously unheard-of precision. Environmental science, medicine, and agriculture will all be significantly impacted by this breakthrough. However, it is important to carefully address the ethical implications of gene editing, especially with regard to human embryos and genetic changes.
- In a similar vein, environmental monitoring has been transformed by remote sensing technologies, which allow researchers to gather data globally. Scientists can monitor climatic patterns, detect deforestation, and evaluate changes in land use by using drones and satellite photos. Although these cutting-edge technologies improve research capacity, they also give rise to questions over data accuracy and environmental effects.

Innovations in Policy and Research Funding

- Research funding is changing because of societal demands, economic challenges, and the drive for innovation. New methods that put an emphasis on multidisciplinary research, teamwork, and societal effect are challenging established financing paradigms.

- The growing focus on impact-oriented funding, in which grants are given out according to the research's possible social benefits, is one noteworthy trend. For example, funding organisations might give top priority to initiatives that tackle urgent global issues like social inequality, public health, and climate change. This change promotes cross-sector collaborations and pushes researchers to match their work with societal requirements.
- Additionally, innovative funding models, such as crowdfunding and public-private partnerships, have emerged as alternative sources of support for research initiatives. These models enable researchers to engage directly with the public and industry stakeholders, fostering a sense of community investment in scientific inquiry.

Prospects for the Future

- A number of new developments and possible strategies are set to influence the direction of scientific research in the future. The growing significance of sustainability and ethical considerations in research procedures is one noteworthy development. A more responsible attitude to scientific inquiry is being fostered by the growing need on researchers to think about the social and environmental effects of their work.
- Additionally, technological developments will keep spurring new approaches to research. Data management, teamwork, and transparency in research could be completely transformed by the combination of blockchain, AI, and machine learning.
- Finally, tackling global issues will need the scientific community to cultivate an inclusive and diverse culture. Accepting a range of viewpoints and experiences can improve scientific research's originality and applicability, which will ultimately result in better answers.

Conclusion:

- In conclusion, the development of novel scientific research methodologies is essential to tackling the intricate problems that modern society faces. The scientific community may increase its influence and relevance by embracing interdisciplinary collaboration, utilising big data and artificial intelligence, encouraging citizen science, and implementing open science principles. Prioritising sustainability, ethics, and inclusivity is crucial as we negotiate the future of research to make sure that scientific inquiry advances society.

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AQUATIC ADAPTATIONS: BIO-INSPIRED INNOVATIONS FROM FISH

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Abstract:

Fish are extremely versatile species that developed numerous unique features to live in different water conditions. These adaptations create a good base for technological inventions and solutions to human problems or improvement of human life. Thus, this paper aims to discuss biomimetic technologies arising from fish research, mainly based on their movement, feeling, and structure. Studying the propulsion efficiency of the fish fins, the high sensitivity of the lateral line and the materials of the scales, researchers can create more efficient materials, undersea vehicles and sensors. Biomimicry works alongside engineering, biology and material science and as such, this paper shows that biomimicry holds high chances of efficiently and sustainably facilitating technologies. The implications of the results reveal that through embracing the quest for knowledge from natural organisms, the modern society can harness solutions to modern day challenges in the field of engineering and architectural design.

Keywords: Swimming, Light Production, Adhesives, Smart Materials.

Introduction:

This chapter aims to reveal some inventions of nature and in particular, the interesting mechanisms utilized in water as innovation is so capricious and unpredictable. Fish a broad group of water dwelling, vertebrate animals adapt various structures and mechanisms to move, exist, and reproduce in aquatic environment (Minich *et al*., 2022). Such adaptations of the bones which have evolved through natural selection provide opportunities for biomimicry, where biology is used to solve various human challenges. Everything from the fish's body shape that has designed to reduce the hydrodynamic drag to the sensory organs internal construction is a triumph of engineering (Gutarra *et al*., 2019). Research in these biological systems has already provided technology breakthroughs as evidenced by underwater vehicles that mimic flischer movement and nanomaterials that mimic fish skins (Jacobstein *et al*., 2017; Aguzzi *et al*., 2021). This chapter stress the relation between original appearances of fish and ongoing technological derivatives of the same, in addition to explore the vast area of bio-inspiration from fish and their physiological, anatomical and behavioral features leading to spectacular advancements in the field of modern-day technology, engineering and designing as highlighted below.

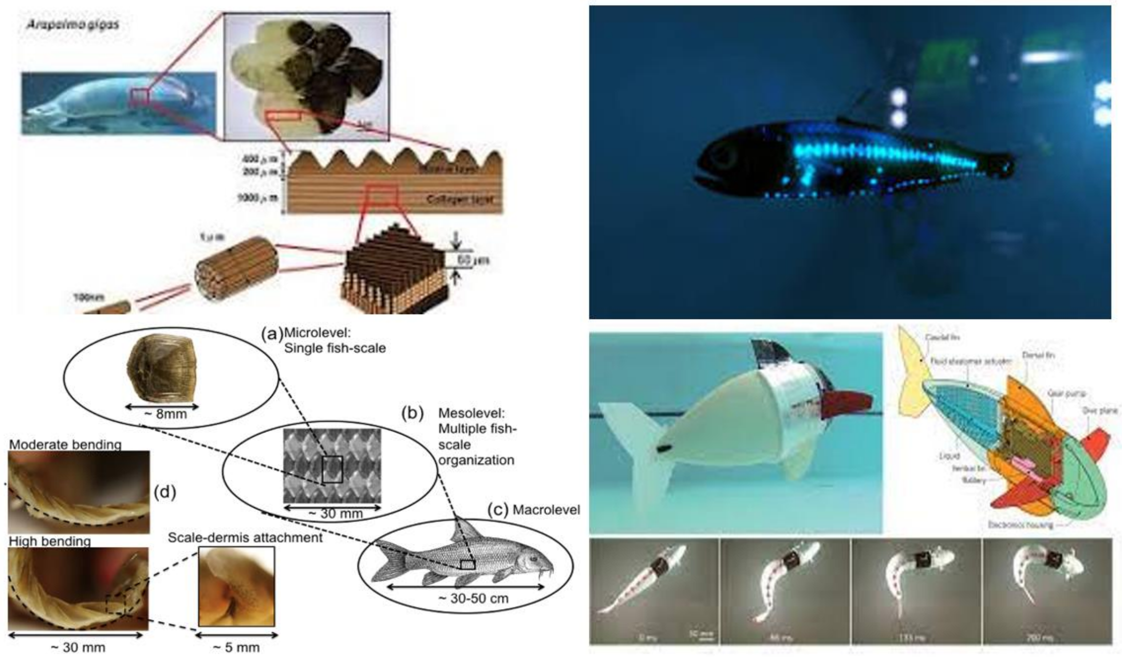

Figure 1: Original appearances of fish and ongoing technological derivatives, bio-inspiration and their physiological, anatomical and behavioural features

1. Hydrodynamic Designs and Propulsion System

This one concerns the design and shaping of objects especially vehicles to enable them to move freely within or on a certain medium more closely being water striving to maximize the stream line, texture and flow characteristics of objects with particular reference to the forces that negatively influence the movement in water. Aquatic animals such as fish have muscular body structures, and have efficient means for moving through water, this is the most obvious source of bio-inspiration (Liao *et al*., 2022). Innovation from fish has been used by engineers to come up with vehicles, submarines as well as underwater drones that have minimal drag in water (Cui *et al*., 2023). Applications of Biosensors on fish scale and skin quality have also resulted to inventing of materials with zero drag and enhanced hydro dynamic strength, resulting to the more enhanced fish moving equipments (Yaseen *et al*., 2021). Fish such as tuna and eel employ the major part of the body and tails for movement in water and following this design the engineers designed more efficient underwater power plants and propellers with greater thrust, energy efficiency and less fuel and power consumption, compared to normal hulls and propellers.

2. Sensory System Absorbing the Non-Absorbable

A sensory system can be described as any structures and specific tissues that are grouped together with all the neural pathways that are used by an organism for the initial processing of stimuli derived from the outer environment. Sensory systems not only offer ability to infer various types of stimuli to the organisms inclusive of sound, light, touch, taste, and smell but also offer important information in areas of survival, direction, and communication (Simpson *et al*., 2016). Every organ is designed to feel different stimuli, then send signals to the brain which will make interpretation of same. Sensory organs especially the eyes and the neural connections that connect into the brain are responsible for the detection of light, and allows reflectors to be aware of a variety of forms, colors and motion (Johnson *et al*., 2019). The ears and the auditory nerves within the organisms' body sense sound waves and allow the organisms to recognize auditory stimuli, for instance, spoken words or music or even noise. Thus, the part of a nervous system, which is located in the nasal cavity, is called the olfactory system; it helps an organism define chemicals existing in the air and discern various scents/fragrances (Poncelet *et al*., 2023). Taste buds that are found in the tongue and mouth parts of the organisms forms the gustatory system which helps in the detection of chemicals dissolved in saliva and thus helps the organisms to be able to differentiate between the various tastes, /as sweet, sour, salty, bitter and umami.

3. Buoyancy and Locomotion to help Manoeuvre to be very active

Floatation is defined as the force with which a fluid, water or air pushes an item placed in it or an item floating on it. This force opposes the gravitational force acting on the object and decide the fate of the object whether to sink or float or will remain in mid-air in the fluid. The force of buoyancy operates by virtue of the Archimedes buoyancy force that the increase in the value of buoyancy is proportional to the weight the fluid displaced by it (Thiam, 2016). Generally, when the buoyant force is equal to or more than the weight of the floating object, then the object rises to the surface and floats. However, if the buoyant force is less than the weight of an object it is supporting then this object will sink. Where the buoyant force is equal to the weight of the object then the object will float at a particular depth in the fluid and will not sink deeper or rise higher.

It is crucial to make and construct objects that float, are secure, and efficient in the media to know the concept of buoyancy in engineering and working with fluids. The control and man ever ability of fish has triggered developmental in the field of robotics and biomimetic design. Robotics engineers have created fish robot looks and swim like fish fins and tails so as to achieve locomotion and also efficient energy (Li *et al.*, 2022). Robots modeled on natural organisms like MIT's Robo Tuna are characterized by their flexible bodies and fins thus have high mobility couple with low energy consumption, and they can be specifically used for underwater surveillance, environmental monitoring and marine research where rigid propellers and their energy hungry mechanisms will not be efficiency (Triantafyllou and Triantafyllou, 1995).

4. Adaptations to Extreme Environments for thriving better

Extreme temperature can therefore loosely be described as temperature that does not fall in the typical category for a given location, environment or season. Most of the time, the extreme temperature conditions may mean either very high temperatures that is, heat or heat waves, or very low temperatures that is, cold or cold snaps (Tye *et al.*, 2022). These two can have major difficulties and perils influence on human being, constructions, environment and even agriculture and other fields, for instance, extreme heat events, can also cause heat inbalance, heat stroke and drought particularly to the elderly, children and persons with health complaints (Bolan *et al.*, 2023). On the other hand, extreme cold events contain risks including frost bite, hypothermia and water pipe and tap freezing checking transportation, agriculture and public services. Apart from this effect, temperature also has long-term repercussion on ecosystems and climate systems, other factors that affects temperature includes glacier melting, rise in sea levels and shift in precipitation patterns.

Fish species inhabiting extreme environments, such as deep-sea trenches and polar regions, have evolved exceptional adaptations for survival in harsh and unsuitable conditions. These adaptations, including specialized metabolic pathways, antifreeze proteins, and pressure-resistant anatomical structures, have inspired innovations in materials science and biotechnology (Glasby *et al.*, 2021). Biomimetic studies of deep-sea fish physiology also have led to the development of pressure-resistant materials for use in deep-sea exploration equipment and underwater habitats (Blasiak *et al.*, 2022). By adopting the adaptive strategies of extremophile fish species such as Atlantic mollies of

Southern Mexico, researchers have developed materials and technologies capable of withstanding extreme conditions, exploring and exploiting the most uninviting environments on Earth.

5. Bioinspired Materials and Structures Contributing to Medical Biotechnology.

Biomimetic materials are materials that are developed artificially, and they are meant to have the structure, characteristics, or performance of biological materials found in water animals such as fish (Ciulla *et al*., 2023). They are coined bio-inspired materials imitating or enhancing certain features of biological systems and evolution and designed to implement or escalate one or multiple biomimic features for specific uses (Wang *et al*., 2020). They may imitate the structural characteristics or possibly the functional characteristics of the material: for instance, the lamellar organisation of fish gills, bone, scale, etc or the adhesive properties of certain fishes. Examples of bioinspired materials include: Examples of bioinspired materials include:

1. **Fish scales inspired superhydrophobic surface:** These surfaces look like the structures on the fish scale which help in the inhibition of water droplets to stick on the surface. The versatility accompanied with fish scales go hand in hand with flexibility and protection has use in creating superior materials for body armours, flexible electronics as well as in the construction industry.
2. **Bone inspired materials:** Substances created to ensure they exhibit the same structure as lightweight bone tissue, which has a collagenic base and mineral crystals (hydroxyapatite) as reinforcements. These materials have been extensively applied for the synthesis of bioactive platform for the regeneration of bone and tissues for engineering.
3. **Bioadhesive Materials:** Following the same concepts, there has been developments of new adhesive technologies based on the several species of fish like the clingfish which have the ability to stick to slippery surfaces; the resulting adhesives are commonly used in the medical field as wound dressings and surgical tapes. Succinctly, there are special composite and adhesive materials similar to mussel and fish glue proteins that can attach to surfaces on condition that they are underwater. These materials are used in different sectors for instances in the medical fraternity it can be used in medical adhesives and even in surgical sealants while in the marine sector, it can be in coatings.
4. **Shark skin:** A distinctive pattern that is on the shark's body and skin comprises tiny projections known as denticles that not only minimize drag but also reduce fouling or

organisms that adhere to the skin surface thereby inspiring extra shell or ship coatings. These coatings improve their speed and efficiency by the elimination of friction and also prohibit the growth of organisms on the hull.

5. **Fish gills:** The well-developed gas exchange system is found in the fish that possesses gills; this fact has encouraged the researchers to come up with improved respiratory systems and artificial gills for medical uses and breathing devices.
6. **Fish illuminance:** Anomalops katoptron more commonly known as splitfin flashlight fish use light at night to locate planktonic prey by creating its producers bioluminescent light with the help of bacteria. Given this quality of production and emmision of light by a fish has fascinated the researchers and scientists to incorporate this mechanism in the appliances used in and underwater at night.

Conclusion:

The biomimetics derived from fish offer rich possibilities for innovation due to the constant attempts to replicate the most efficient, biological, and environmentally friendly processes of the fish. Fish have numerous structures consisting of light weight skeletons, flexible fins, armor like scales, adhesives, which have been used in the synthesis of biomimetic structures and material. Scientists and engineers have been applied biomimetic design to make lightweight flexible externally ribbed structures that have been adopted in aerospace, automotive and sporting industries. Still, biomimetic studies replicating the pattern of fish scales have produced protective clothing materials that have higher endurance and shockproof that can find use in military and protective clothing. In materials and structures science, the study of fish and their complexity of structural organizations led engineers to invent strengthened flexible and lightweight materials across from transport, defence, robotics, propulsion systems, material sciences, medical technologies and much more, so the study of fish and adaptations will proceed to fuel innovative alchemist's carousel of inventions in various disciplines.

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