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CTFC 2025

CONFERENCE ON TECHNOLOGIES FOR FUTURE CITIES (CTFC 2025)



THEME: 2030 AGENDA FOR SUSTAINABLE DEVELOPMENT

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12TH – 13TH DECEMBER, 2025

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CTFC 2025

CONFERENCE ON TECHNOLOGIES FOR FUTURE CITIES

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ABOUT PILLAI SCHOOL OF ENGINEERING UNDER PILLAI UNIVERSITY

Pillai School of Engineering (Formerly Pillai College of Engineering - PCE), was established in the year 1999 with a cherished desire to mold engineers in developing new age technology with respect for the environment. This objective is fulfilled by equipping our students with cutting edge technology through quality education, practical training, and industry interaction. We are located amidst a beautiful green campus in Navi Mumbai and offer Undergraduate, Postgraduate and Research programs in Engineering. We are recipients of several National and International awards and grants. The excellent infrastructure, well equipped laboratories, experienced faculties along with magnificent atmosphere and ambience makes us an ideally suited institution for growth and development of soul and mind.





PRINCIPAL'S ADDRESS



Dr. Sandeep Joshi
Principal
Pillai School of Engineering, New Panvel

In rapidly developing nations like India, urban expansion often leads to challenges such as inadequate infrastructure and environmental pressures resulting from unplanned growth. In response, scientists and engineers worldwide are exploring technological solutions to build smarter, more sustainable cities. Aligned with this vision, Pillai School of Engineering organizes Conferences on Technologies for Future Cities, focusing on innovative software, hardware, and governance approaches to support sustainable urban development.

I am delighted to welcome all participants to this conference, a platform that brings together innovative research and emerging ideas across diverse engineering disciplines. The work presented here reflects exceptional standards of technological innovation, methodological rigor, and relevance to evolving industrial and societal needs. These contributions strengthen our institution's commitment to promoting excellence in engineering education, research, and sustainable development. I sincerely commend all researchers and delegates for their dedication, and I encourage continued efforts toward creating impactful and future-oriented engineering solutions.

ABOUT CTFC 2025

Cities in developing countries are rapidly expanding. India has 438 cities with a population of more than 100,000 people, accounting for 11% of the world's cities. It is expected that the urban population will be doubled in next 25 years. Unfortunately, the development is unplanned and chaotic, resulting in inequitable distribution of public services, costly housing, a lack of adequate streets and roads, and insufficient open spaces. Scientists and engineers all over the world are looking for technological solutions to problems such as poor urban planning, non-availability of affordable housing, deficiency in water supply or electricity, unorganized traffic, poor quality public transport and parking facilities, poor healthcare system, waste management, air and water pollution, etc. Pillai School of Engineering has taken a timely lead and has started a series of conferences on "Technologies for Future Cities" to examine some of the challenges raised above. The inaugural conference took place on January 8-9, 2019, followed by an alternating cycle of a one-day consortium and a full conference each year. There were about dozen invited talks followed and about 250 scientists and engineers attended the conference. The full details of the conferences are available on www.futurecities.mes.ac.in.

ABOUT PANVEL, NAVI MUMBAI

Panvel, the first Municipal Corporation of Raigad, is a historic town known for its lakes, temples, forts, and proximity to a wildlife sanctuary. Strategically located on the outskirts of Mumbai, it is emerging as Maharashtra's key transportation hub, well-connected by road, rail, and air. The conference venue, Pillai School of Engineering, New Panvel, is easily accessible via direct local trains from major Mumbai stations and is approximately 90 minutes from Mumbai airport. Travelers can reach the venue from Chhatrapati Shivaji Maharaj International Airport, with both domestic and international terminals offering convenient access. The conference venue, Pillai School of Engineering, New Panvel, is easily accessible via direct local trains from major Mumbai stations and is approximately 90 minutes from Mumbai airport.





CTFC 2025

CONFERENCE ON TECHNOLOGIES FOR FUTURE CITIES

THEME : 2030 AGENDA FOR SUSTAINABLE DEVELOPMENT

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Conference on Technologies for Future Cities 2025 (CTFC-2025)

12th - 13th December 2025

Program Schedule



Time	Activity	Venue
Day 1: 12th December 2025		
8.30 - 9.30am	Registration Breakfast	Reception Area Old Canteen Area
9.30 - 11.15am	<u>Inauguration</u> Welcome Address by Dr. Sandeep Joshi, Principal Inaugural Address by Chief Guest Dr. Sachin Kore, Director, VJTI Mumbai Keynote Address by Guest of Honor Dr. Archis Yawalkar, aSai Viswa speciality Chemicals	Auditorium 7th Floor
11.15 - 11.30am	Tea Break	
11.30am - 12.15pm	Plenary Talk 1 - Dr. Sajeev Nair, CEO, Asian School of Science and Engineering Technology	
12.15 - 1.00pm	Plenary Talk 2 - Dr. Ajit Salvi, Director, RCUES of AILSG, Mumbai	
1.00 - 2.00pm	Lunch	Old Canteen Area
2.00 - 3.30 pm	Parallel Session of Contributed Oral Papers Session A- Digital Transformation in Cities [Paper ID-6,35,43,42,54,66,90] Session B - Environmental & Social Impacts [Paper ID-12,19,39,80,82,98] Session C - Environmental & Social Impacts [Paper ID-17,18,64,88,93, 84] Session D - Future Urban Infrastructure [Paper ID-50,85,91]	G-501 G-502 G-503 G-504
3.30 - 4.15pm	Plenary Talk 3 - Mr. Neil Sawant, Founder & CEO, NUOS	Auditorium 7th Floor
4.15 - 5.00pm	Plenary Talk 4 - Dr. Chitrarekha Kabre, SPA, New Delhi	
5.00 - 5.30pm	Networking and High Tea	Old Canteen Area
5:30pm Onwards	SPIC MACAY Concert Flute Recital by Pt.Ronu Mazumdar	Auditorium



Conference on Technologies for Future Cities 2025 (CTFC-2025)

12th - 13th December 2025

Program Schedule



Time	Activity	Venue
Day 2: 13th December 2025		
9:00 – 10:00am	Registration Breakfast	Reception Area Old Canteen Area
10.00 - 10.45am	Plenary Talk 5 - Mr. Gaurav Sharma, Meta Infotech Limited	Auditorium 7th Floor
10.45 - 11.30am	Plenary Talk 6 - Dr. Kamal C. Vora, Program Director, NAMTECH	
11.30-11.45am	Tea Break & Networking	5th Floor
11.45 am - 1.00pm	Parallel Session of Contributed Oral Papers Session E- Digital Transformation in Cities [Paper ID-31,53,59,60,86] Session F - Environmental & Social Impacts [Paper ID-9,32,46,58,62,72,77] Session G - Future Urban Infrastructure [Paper ID-24,33,34,38,40,45]	G-501 G-502 G-503
1.00 - 2.00pm	Lunch	Old Canteen Area
2.00 - 3.30pm	Poster Session [Paper ID:21,48,49,78,94,95,99,102]	Stilt Area
3.30 - 4:00pm	Startup Innovator's Forum - Dr. Seema Regi, Mr. Vishal Stephen	Auditorium 7th Floor
4.00 - 4.45pm	Plenary Talk 7 - Mr. Milind Kamble, TCS	
4.45 - 5.30pm	Valedictory Prize Distribution Address by Chief Guest Vote of thanks	
5.30 - 6.00pm	Networking and High Tea	Old Canteen Area



CTFC 2025

CONFERENCE ON TECHNOLOGIES FOR FUTURE CITIES

THEME : 2030 AGENDA FOR SUSTAINABLE DEVELOPMENT

CHIEF GUEST



*Dr. Sachin Kore
Director, VJTI Mumbai*

KEYNOTE ADDRESS



*Dr. Archis Yawalkar,
CEO, aSai Viswa speciality
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PLENARY TALKS



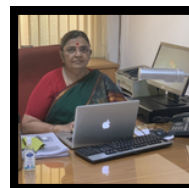
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CEO, Asian School of Science and
Engineering Technology*



*Dr. Ajit Salvi
Director,
Regional Centre for Urban &
Environmental Studies (RCUES)
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PLENARY TALKS



Common Skills for All – Self-Empowerment, Life Skills, and Interpersonal Strength

*Dr. Sajeed Nair
CEO, Asian School of Science and Engineering Technology*

Abstract

Many corporate professionals often believe that skills such as self-empowerment, life skills, and interpersonal strength are essential only for those working in organizations, factories, plants, or offices. However, I personally believe these skills are vital for everyone – from kindergarten children, school and college students, undergraduates, graduates, and research scholars to homemakers, artists, sports professionals, and individuals across every walk of life. As we all know, life skills such as problem-solving, critical thinking, effective communication, decision-making, creative thinking, interpersonal relationships, self-awareness, empathy, and coping with stress and emotions are fundamental to personal and professional growth. While the level of proficiency may differ between children and adults, the importance of these skills remains universal. Developing such skills is essential because it helps us enhance the attributes and qualities crucial for effective performance – not only in the workplace but in every sphere of life. By continuously developing these abilities, we embark on a journey of personal growth that empowers us to reach our fullest potential and achieve our goals efficiently and meaningfully.



PLENARY TALKS



Environmental and Social Impacts in Cities: The Role of Social Equity and Sustainable Energy Solutions

Dr. Ajit Salvi

Director,

Regional Centre for Urban & Environmental Studies (RCUES)

of All India Institute of Local Self Government (AIILSG), Mumbai

Abstract

India's rapid urbanization is reshaping its social, environmental, and energy landscapes, creating both unprecedented opportunities and deepening vulnerabilities. With over half the global population now living in cities and India projected to host nearly double the current urban residents by 2050, the pressures on urban ecosystems, infrastructure, and public health continue to intensify. Heatwaves, air pollution, service deficits, energy poverty, and expanding informal settlements demonstrate that environmental burdens are not evenly distributed; they disproportionately impact low-income and marginalized communities. Incidents such as Mumbai's heat wave and Delhi's severe air-pollution episodes highlight how climate and environmental stresses intersect with social inequities, amplifying health risks and economic hardship for the urban poor. This paper examines the intertwined challenges of environmental degradation, unequal access to basic services, and the uneven distribution of clean energy benefits across Indian cities. It evaluates how deficits in housing, drainage, water supply, sanitation, and electricity undermine resilience, while fossil-fuel dependency and rising energy demand further strain urban systems. Drawing on national datasets, city-level assessments, and emerging clean-energy innovations, the study identifies pathways through which sustainable energy solutions such as rooftop solar, energy-efficient buildings, decentralized systems, and digitalized grids can advance both climate goals and social justice.

By centering social equity within the clean-energy transition, Indian cities can reduce emissions, enhance resilience, lower household energy costs, and improve health outcomes for the most vulnerable groups. The paper proposes an implementable roadmap for city governments, emphasizing institutional capacity, equitable access, participatory planning, and integrated financing mechanisms. Ultimately, the research argues that building socially inclusive and energy-secure cities is essential for achieving Sustainable Development Goals commitments, India's Net-Zero 2070 vision, and the broader goal of Viksit Bharat 2047.



PLENARY TALKS



Devices to Decisions: Leveraging IoT for Smart Automation and Digital Innovation

Mr. Neil Savant

Founder & CEO at NUOS Home Automation

Abstract

As cities evolve into complex, interconnected systems, the Internet of Things (IoT) has emerged as a foundational technology enabling data-driven urban transformation. This plenary session explores the broad potential of IoT to connect physical devices with digital intelligence, supporting smarter decision-making and automated city services. The talk will outline the opportunities created when sensors, networks, and analytics converge—ranging from operational efficiency to new digital services that enhance urban living. It will also touch upon the considerations that accompany widespread IoT adoption, including security, governance, interoperability, and the need for human-centric design. By presenting key ideas, current trends, and future possibilities, this session aims to provide a holistic view of how IoT can serve as a catalyst for innovation in the cities of tomorrow.



PLENARY TALKS



Regenerative Design Approach for the Built Environment

Dr. Chitrarekha Kabre
SPA, New Delhi

Abstract

Over the past half-century, a discourse emphasizing that the environmental health of our earth is profoundly affected by the design of our built environment has emphatically shaped high-performance (green) building practices and associated building regulations (standards and codes), building environmental assessment methods and sustainability assessment systems. The trajectory of environmentally responsive design as applicable to the built environment delineates the transition from technological (high-performance) design paradigm to biocentric (ecological) design paradigm, Figure 1. It is professing a sustainability framework in synergy with nature or ecosystem not only to preserve the environment but also to revitalize and regenerate to have net positive environmental benefits for the living world. This implies a living or whole-systems approach, a more expansive notion of the built environment, one where dynamic relationship exists between a greater number of built and unbuilt elements and where a balance, sustainable relationship between these elements is explored and harnessed. The systems approach in the present context is a much-needed call for building professionals to redefine architecture and adopt principles of regenerative design and examine how it does (or does not) relate to their everyday practice. Mies van der Rohe said that 'less is more'; in the present context a better way of putting it may be, as Alexandro Tombazis says, 'less is beautiful.



PLENARY TALKS



From Smart to Secure: Cyber Defence for the Cities of Tomorrow

Mr. Gaurav Sharma
Meta Infotech Limited

Abstract

The talk will explore how cybersecurity will shape the success and safety of smart cities, focusing on India's Smart Cities Mission. It will outline the rise of digitally connected urban infrastructure through Integrated Command and Control Centres and highlight India's efforts within a global smart-city market worth hundreds of billions of dollars. Against the backdrop of escalating cyber threats like ransomware, IoT attacks, and data breaches, the vulnerabilities in urban systems and governance will be discussed. The session will conclude with a roadmap built on four pillars – policy and governance, secure architecture, resilience, and skills – stressing that cybersecurity by design is vital for building safe, trusted, and future ready smart cities.



PLENARY TALKS



Smart Mobility in Smart Cities

Dr. Kamal C. Vora
Program Director, NAMTECH

Abstract

The rapid transformation of urban mobility in Asia is driven by rising consumerism, digitalization and economic growth, resulting in challenges such as congestion, pollution, safety concerns and increased energy demand. This presentation explores how Smart Mobility—enabled by electric vehicles, shared mobility models, connected platforms, intelligent transportation systems and autonomous driving technologies—can address these issues and support the development of sustainable smart cities. It highlights global and Asian mobility trends, the shift toward ACES (Autonomous, Connected, Electric & Shared) solutions, advancements in vehicle connectivity (V2V, V2I, V2X), and the integration of AI-driven systems for safety, efficiency and user-centric experiences. The talk also presents technological building blocks such as ADAS, sensor fusion, autonomous navigation and the evolution of electric and autonomous vehicles. Finally, it emphasizes ecosystem collaboration across industry, academia and skill development communities to drive innovations that enable safe, accessible, efficient and environmentally responsible mobility for the future.



PLENARY TALKS



Challenges and Opportunities in the Development of Smart Cities

*Mr. Milind Kamble,
Vice President & Delivery Centre Head
Tata Consultancy Services Ltd.*

Abstract

The evolution of smart cities stands at the intersection of technology, urban planning, and community engagement, presenting both significant challenges and promising opportunities for researchers and practitioners. This plenary session will explore the multifaceted journey of smart city development worldwide, drawing lessons from both successful implementations and notable failures. While cities like Singapore and Barcelona have pioneered the integration of digital infrastructure, data-driven governance, and citizen-centric services to enhance urban living, others have struggled to overcome barriers such as inadequate funding, fragmented leadership, and privacy concerns. Failed projects, including cities in Asia and Middle East highlight the pitfalls of top-down planning, lack of community involvement, and unsustainable economic models. Key challenges in smart city development include securing robust and scalable technology, ensuring equitable access, maintaining data privacy, and fostering cross-sector collaboration. At the same time, large number of opportunities in leveraging artificial intelligence, the Internet of Things, and sustainable practices to create cities that are resilient, inclusive, and adaptive to future needs. India provides opportunities in terms of developing such smart cities anew at the same time creating engineering jobs for engineers such as you. The talk will make the participants to think not only of a career but also making a smarter future and better India and world.



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Portable Antenna for Radio Astronomy

Aditi A. Patil¹, Shravan V. Shetty², Arnav A. Sapate³, and Ajit Saraf⁴

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Abstract: This paper presents the design and implementation of a Portable Antenna System for Radio Astronomy capable of autonomously detecting and tracking radio signals from celestial sources, particularly solar emissions. The proposed system utilizes a Ku-band parabolic dish antenna integrated with a Low Noise Block Feed (LNBF) for signal reception and down-conversion. An RTL Software Defined Radio (RTL-SDR) receiver is employed for signal acquisition and processing, while a Vicharak Shrike Lite development board based on the RP2040 microcontroller performs control and automation tasks. Elevation adjustment is achieved using a NEMA stepper motor coupled with a mechanical linkage system, whereas azimuthal movement and mobility are provided through a four-wheel mecanum platform driven by DC motors. The system performs autonomous scanning and aligns itself toward the direction corresponding to the maximum received signal strength. Experimental testing under direct sunlight conditions demonstrated successful signal acquisition and autonomous positioning using real-time feedback from the software-defined radio subsystem. The proposed design provides a low-cost, portable, and scalable platform suitable for educational radio astronomy experiments and future autonomous astronomical observation systems.

Keywords: Radio Astronomy, RTL-SDR, RP2040, Portable Antenna, Ku-Band, LNBF, Signal Tracking, Autonomous Scanning.

1. Introduction

Radio astronomy is credited with enabling us to know the universe by observing celestial happenings through the means of radio frequency radiation. Unlike optical astronomy, founded on visible light, radio astronomy detects signals in the radio band released by celestial bodies such as the Sun, stars, pulsars, and galaxies. Historical radio telescopes, however, are enormous, advanced, and expensive arrangements, which restrict them to limited research, educational pursuits, and field tests. The limitation has encouraged the necessity for a light, low-cost, and portable alternative with the capacity for detecting and processing radio signals from celestial bodies.

The purpose of this project is to develop a Portable Antenna System for Radio Astronomy capable of autonomously detecting and orienting itself toward the direction of maximum

received radio signal strength. The proposed system is designed around a commercially available Ku-band parabolic dish antenna equipped with a Low Noise Block Feed (LNBF), an RTL Software Defined Radio (RTL-SDR) receiver, and a Vicharak Shrike Lite development board based on the RP2040 microcontroller. The antenna platform incorporates an elevation control mechanism driven by a NEMA stepper motor and a mobility platform consisting of four mecanum wheels driven by DC motors. This configuration enables both angular adjustment and omnidirectional movement, allowing the antenna to autonomously scan its surroundings and optimize its orientation based on received signal strength measurements. This project shows the feasibility of integrating radio frequency sensing, embedded control, and robotic mobility to construct a flexible, portable radio telescope. The system presented here offers an affordable solution for student-level academic research, classroom demonstrations, and prototype-level astronomical research. It also provides an entry for future technologies such as automatic Sun-tracking, real-time data acquisition, and observation network in the cloud, and it makes radio astronomy more accessible to students and researchers.

2. Literature Review

Pranshu Mandal, Devansh Agarwal, Pratik Kumar, Anjali Yelikar, Kanchan Soni, and Vineeth Krishna T [1] introduced the "Everyday Radio Telescope", a low-cost and portable installation with the goal of illustrating radio astronomy principles for educational application. The setup detects solar emissions in the Ku-band using an off-the-shelf satellite TV dish and an LNB. It uses an RTL-SDR dongle to receive the signal and acquire data and software-based spectral analysis. The project was able to show that radio astronomical observations with significant value could be conducted using readily accessible consumer-grade components. This research lays the groundwork for creating low-cost radio telescopes replicable in colleges and small research centers.

A. Simon et al. [2] presented "A Portable Many-Element Coherent Receiver System for Passive Radar and Space Domain Awareness (2023)", which is concerned with the design of a scalable receiver architecture for space situational awareness. In the paper, the usage of several synchronized receiver elements operating coherently to receive weak signals from space objects and passive radar sources is emphasized. It describes the difficulties in synchronization, timing accuracy, and phase coherence of distributed sensors. Modular and portable nature of the system illustrates that low-cost, small-scale hardware can provide highly sophisticated space and radar monitoring applications.

C. Lang [3], in "Low-Cost SDR Radio Telescopes for Amateur Astronomy," pointed out the revolutionary impact of Software Defined Radio (SDR) to bring radio astronomy within the reach of amateurs. The paper explains how SDR platforms like RTL-SDR can be made to work with parabolic dishes and LNBS to pick up celestial signals, such as solar and galactic noise. The author demonstrates the trade-offs of SDR-based equipment in terms of affordability, flexibility, and performance over analog systems. This research supports the viability of employing SDRs within low-cost radio telescopes, directly in line with the hardware approach implemented in the current project.

G. Swarup [4], in "Development of Radio Astronomy in India", traced the historical development of radio astronomy in India and indigenous development of large facilities like the Ooty Radio Telescope and Giant Metrewave Radio Telescope (GMRT). The fifth chapter of this book deals with how frugal engineering strategies and creative designs brought India to the forefront of world radio astronomy. It places great value on cost-effective instruments and local fabrication facilities. Swarup's approach to making high-quality observations at reasonable cost is an inspiration for creating small and portable systems such as the one described in this project.

The Thought Emporium YouTube channel [5] worked through a useful project called "How to Build a Radio Telescope (See Satellites 35,000 km Away!)". The video provides a step-by-step tutorial on how to build a functional radio telescope with a satellite dish, LNB, and SDR receiver. It touches on issues like antenna alignment, noise suppression, and real-time visualization of the signal. The project managed to receive satellite signals and solar emissions and demonstrates that with DIY and educational projects, it is possible to obtain scientifically useful data. The ease of use and functionality of this configuration offered real-world experience in assembling the mechanical and electrical infrastructure for the prototype of this project.

Paridhi Goyal and Dr. Surendra Kumar Agrawal [6] authored "A Review on Software Defined Radio (SDR) in Communication", in which the architecture, adaptability, and realization of SDR are presented within different communication systems. The article describes how SDR technology substitutes conventional hardware elements with reconfigurable software components, allowing flexibility in more than one frequency band and protocol. The article also describes the use of SDR in contemporary wireless communication, cognitive radio, and research use. The review supports the significance of SDR in signal capture and processing for the suggested antenna system, allowing flexible observation in radio frequency ranges.

J. Krumm [7] introduced an ESP32 microcontroller-controlled integrated prototype radio telescope integrated with an SDR receiver in "Portable Radio Telescope System Using ESP32 and SDR." The article is centered on low-power embedded control, automation, and remote data acquisition, demonstrating that IoT-capable microcontrollers can efficiently control antenna motion and capture signals. This piece of work directly mirrors the architecture of the suggested system, offering an established point of reference for integrating SDR technology with ESP32 for portable astronomical signal detection.

3. System Design

The proposed Portable Antenna System for Radio Astronomy is designed to autonomously detect, monitor, and track radio-frequency signals received from celestial sources, particularly solar emissions. The system integrates radio-frequency reception hardware, embedded control electronics, signal-processing software, and a mobile positioning platform into a compact and portable architecture.

The overall system consists of three major subsystems:

- **RF Reception and Signal Processing Unit**
- **Automation and Control Unit**
- **Mobility and Positioning Unit**

The RF reception subsystem comprises a commercially available Ku-band parabolic reflector antenna integrated with a Low Noise Block Feed (LNBF). The LNBF amplifies weak incoming radio-frequency signals and performs frequency down-conversion. Although the observed signals originate in the Ku-band region (10.7–12.75 GHz), the RTL Software Defined Radio (RTL-SDR) receiver cannot directly process frequencies in this range. Therefore, the LNBF converts the received signal into an intermediate frequency (IF) range of approximately 950–2150 MHz, which can subsequently be processed by the RTL-SDR receiver. The digital signal acquisition subsystem is built around an RTL-SDR V4 receiver. The receiver converts the down-converted analog RF signals into digital data and transfers them to a host computer for real-time analysis using SDR++ and GNU Radio software environments. The automation subsystem employs a Vicharak Shrike Lite development board based on the RP2040 microcontroller. The controller executes antenna scanning algorithms, processes received signal information, and controls the positioning mechanism to maximize received signal strength. The mobility subsystem consists of a

NEMA stepper motor coupled to a linkage mechanism for elevation control and a four-wheel mecanum platform driven by DC motors for omnidirectional movement. This arrangement allows the antenna to perform autonomous scanning and orientation adjustment while maintaining portability.

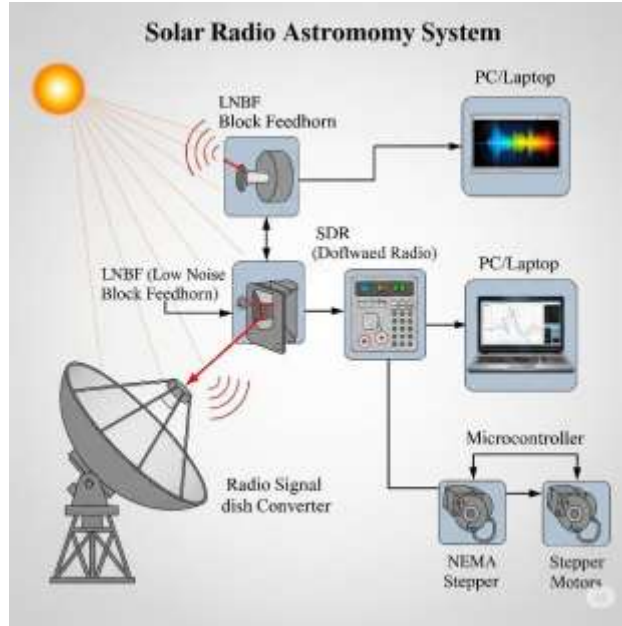


Fig. 1. System Design

4. Hardware Implementation

The entire hardware implementation can be broken down into various main subsystems:

4.1. Antenna and RF Front-End:

The LNBF parabolic dish antenna is the primary receiving unit. The LNBF downconverts and amplifies high-frequency Ku-band signals into lower intermediate frequencies that the RTL-SDR receiver can process.



Fig 2 Parabolic Antenna

4.2. Signal Receiver (RTL-SDR V4):

The dongle RTL-SDR V4 translates analog RF signals into digital data. It communicates with a host computer operating SDR# or GNU Radio for real-time spectral analysis and monitoring of the signal strength.



Fig 3 RTL-SDR V4

4.3. Control Unit (Vicharak Shrike Lite development board):

The automation subsystem employs a Vicharak Shrike Lite development board based on the RP2040 microcontroller. The controller generates motor-control signals, executes antenna-scanning algorithms, and coordinates communication between the positioning system and the signal-processing subsystem. The controller continuously evaluates signal-strength information and determines the optimal antenna orientation required for maximum signal reception.



Fig 4 Vicharak Shrike Lite development board

4.4 Motion System:

Elevation Control: A NEMA stepper motor is connected to a mechanical linkage assembly used to tilt the parabolic dish vertically, allowing for accurate elevation angle adjustment.



Fig 5 NEMA 17 Stepper motor

Azimuth and Mobility: Four mecanum wheels were 3D printed, with each being powered by a DC motor, for omnidirectional motion. This offers the system the capability of rotating around its vertical axis for azimuth motion and reorienting itself in the observation space if necessary. Full mobility is achieved by the base moving forward, backward, laterally, and rotating due to the coordinated motion of the four stepper motors.

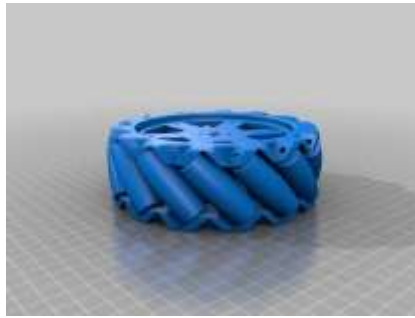


Fig 6 3D Printed Mecanum Wheels

4.5. Power Supply:

The ESP32, stepper motor drives, and the LNBF are supplied power from a regulated DC power supply. Proper filtering prevents minimal electrical noise from interfering with the RF receive system.

This hardware integration enables the antenna to move, orient, and stabilize itself autonomously while searching for a signal, thus enabling efficient and accurate observation.

5. Software Implementation

The software module manages motor control, signal capture, and automation logic for autonomous aligning and scanning.

5.1. Microcontroller Programming:

The Vicharak Shrike Lite controller is programmed using the Arduino development environment. The firmware is responsible for generating motor-control signals, managing scan sequences, and executing positioning algorithms. The controller performs periodic antenna movement while simultaneously monitoring received signal levels to determine the optimal antenna orientation.

5.2. Signal Processing Environment:

RTL-SDR V4 is integrated with SDR# and GNU Radio for real-time spectral analysis.

- SDR# offers a simple-to-use graphical frontend to view power levels and frequency spectra.
- GNU Radio allows for sophisticated digital-signal-processing (DSP) flowgraphs for signal-strength measurement, filtering, and data recording.

These tools, in combination, support precise visualization and signal-strength measurement of variations associated with antenna orientation.

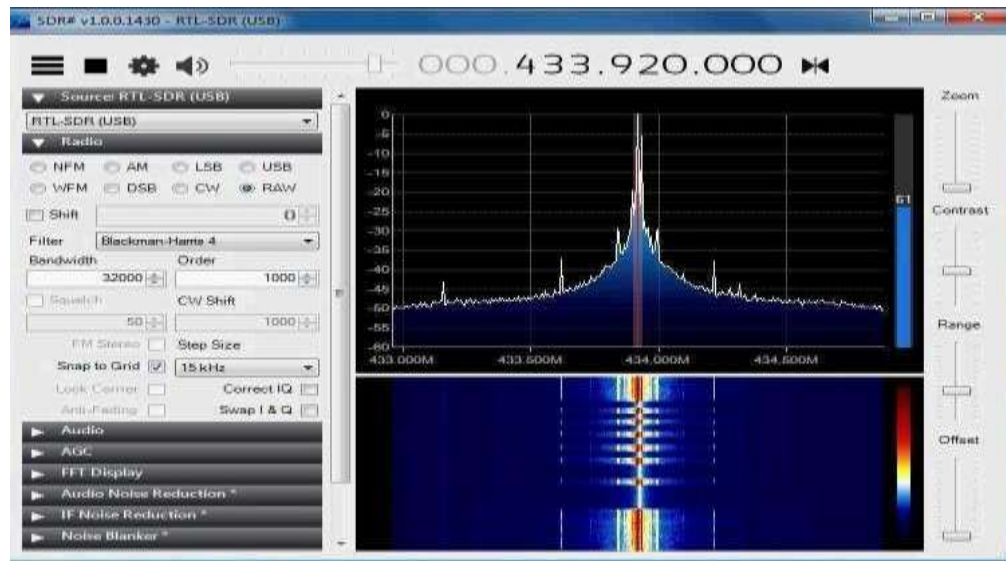


Fig 7 SDR# Software waterfall

5.3. Graphical User Interface

A custom graphical user interface was developed to provide real-time visualization of signal parameters. The interface displays:

- Received Signal Strength Indicator (RSSI)
- Noise Floor
- Signal-to-Noise Ratio (SNR)
- Operating Frequency
- Elevation Angle
- Scan Progress The interface assists operators in monitoring system performance and validating antenna alignment.

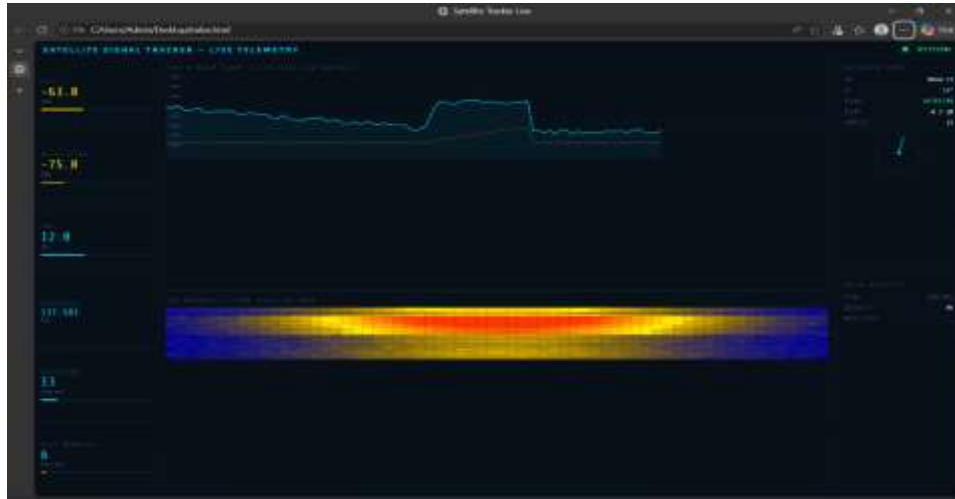


Fig. 8. Custom graphical user interface for signal monitoring.

5.4. Automation Algorithm:

The proposed system utilizes a feedback-based scanning algorithm for autonomous signal acquisition. The operational sequence is summarized as follows:

1. Initialize antenna at a predefined position.
2. Perform systematic elevation scanning.
3. Measure signal strength at each position.
4. Store received signal values.
5. Identify the position corresponding to maximum signal strength.
6. Reposition the antenna toward the strongest signal.
7. Maintain alignment and continue monitoring signal variations.

6. Results and Discussion

The developed prototype was successfully assembled and experimentally evaluated under direct sunlight conditions. The system integrated a Ku-band parabolic reflector antenna, LNBF, RTL-SDR V4 receiver, Vicharak Shrike Lite controller, elevation positioning mechanism, and mecanum-wheel mobility platform.



Fig. 9. Portable Antenna setup

During experimentation, radio-frequency signals received by the antenna were amplified and down-converted by the LNBF before being processed by the RTL-SDR receiver. The custom graphical interface continuously monitored signal-strength parameters and antenna orientation.

The measured RSSI exceeded the observed noise floor by approximately 12 dB, indicating successful signal detection above background noise levels. The graphical interface clearly displayed signal-strength variations corresponding to changes in antenna orientation. The elevation positioning mechanism demonstrated smooth and repeatable movement, while the mobility platform enabled flexible antenna repositioning. The autonomous scanning algorithm successfully identified signal peaks and adjusted antenna orientation accordingly. These results validate the feasibility of integrating software-defined radio technology, embedded control systems, and robotic mobility into a portable radio astronomy platform suitable for educational and experimental applications. Future work will include automated solar tracking, long-duration observations, cloud-based data logging, and detailed antenna characterization involving gain, beamwidth, and sensitivity measurements.

Acknowledgment

We wish to extend our sincere gratitude to Dr. Monika Bhagwat for her invaluable expertise, guidance, and encouragement throughout the duration of this project. Her dedication, time, and motivation were instrumental in its successful completion. We are deeply indebted to Pillai College of Engineering for the provision of excellent facilities, which greatly facilitated the execution of this report. Special thanks are also due to the Maker's Studio for their assistance in 3D printing the mecanum wheels, a pivotal element of our project. Also thanks to Spark Racing Team for letting our team use their workshop for assembly and testing purposes.

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Improving Social Media Abuse Detection Using Heuristic Preprocessing and Machine Learning

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Abstract.

In today's world, social media platforms such as Twitter, Facebook, Instagram, and Reddit serve as the primary means of communication. Unfortunately, this has led to the widespread use of abusive or hateful language online. Automatic detection of such language is critical, as manually curating rules for every variation of slang or abusive term is infeasible. This research introduces a hybrid heuristic-machine learning framework designed to improve abuse detection accuracy using the Twitter Hate Speech dataset. A heuristic preprocessing module first normalizes slangs and abbreviations through a custom-built Python dictionary, transforming them into standard language before feeding into ML models. The preprocessed data is vectorized using TF-IDF and augmented with engineered features such as sentence length and bad word counts. Among multiple models tested—Random Forest, Support Vector Machine and logistic Regression —Random Forest achieved the best accuracy of 96% with an F1-score of 0.83. The results show that intelligent preprocessing significantly enhances detection performance.

Keywords: Hate Speech Detection, Machine Learning, Heuristic Preprocessing, Twitter Dataset, Text Classification.

1) Introduction

- 1.1 Social media platforms such as Twitter, Facebook, Instagram, and Reddit have transformed the way people communicate and share information. Although these platforms provide users with unprecedented freedom of expression, they have also facilitated the spread of hate speech, abusive language, cyberbullying, and offensive content. Such harmful interactions negatively affect individuals and communities and emphasize the need for effective automated moderation systems.
- 1.2 Traditional rule-based approaches rely on manually crafted dictionaries and predefined patterns. However, these methods struggle to cope with the dynamic nature of online language, where users frequently employ abbreviations, slang expressions, and intentionally modified spellings to evade detection. Machine learning techniques have demonstrated promising results in this domain; nevertheless, their performance is often degraded by noisy and highly informal textual data.
- 1.3 To address these challenges, this work presents a hybrid heuristic-machine learning framework that incorporates a custom preprocessing module capable of normalizing slang expressions before feature extraction and classification. The proposed approach improves feature quality and enhances the ability of machine learning models to identify abusive content more accurately.
- 1.4 The major contributions of this work are summarized as follows:
 1. Development of a heuristic preprocessing module for slang and abbreviation normalization.
 2. Integration of heuristic preprocessing with conventional machine learning techniques.
 3. Extraction of TF-IDF and lexical features to improve text representation.
 4. Performance evaluation of multiple machine learning models using the Twitter Hate Speech dataset.

2) Methods and Materials

2.1 Dataset

The Twitter Hate Speech dataset obtained from Kaggle was used in this study. It contains approximately 31,962 labeled tweets categorized as Hateful and Neutral.

2.2 Heuristic Preprocessing Module

A custom Python dictionary was developed to expand short forms and slangs into their complete forms. Example: {'wtf': 'whatthefuck', 'b\$dk': 'bhosdike', 'sht': 'shit'}. This normalization step helps ML models correctly interpret hidden abusive language patterns.

2.3 Feature Extraction

TF-IDF vectorization was used to transform textual data into numerical representations. Additionally, auxiliary features such as sentence length, number of bad words, and good words were extracted.

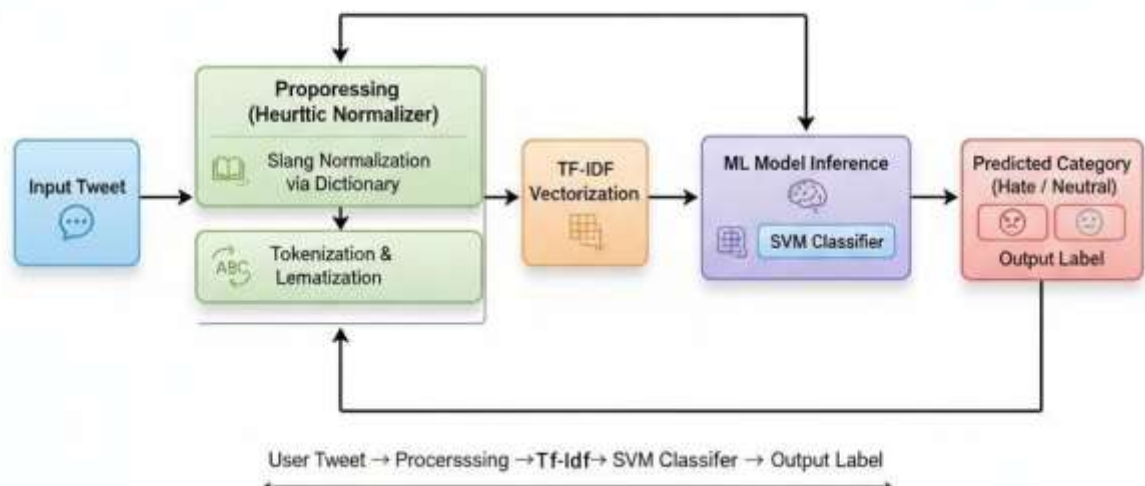
2.4 Machine Learning Models

Three ML models were evaluated: Random Forest, Support Vector Machine (SVM), and Random Forest. A pipeline combining preprocessing and model inference was implemented using Scikit-learn.

3 Experimental Setup

The experiments were conducted on a system with an Intel i3 11th Gen processor and 8 GB RAM. The software environment included Python 3.12, Scikit-learn, NLTK, Pandas and NumPy.

3.2 Heurtic—ML Hybrid Workflow



4 Results and Discussion

Model	Accuracy	Precision	Recall	F1-score
Logistic Regression	0.9521	0.9330	0.6740	0.7406
SVM (Linear)	0.9611	0.9271	0.7510	0.8126
RandomForest	0.9637	0.9239	0.7762	0.8319

The Random Forest model achieved the highest performance among all tested algorithms, obtaining an accuracy of 96% and an F1-score of 0.83.

This outcome demonstrates that the proposed heuristic preprocessing module effectively enhances the interpretability and robustness of traditional machine learning models against informal and obfuscated abusive language. The improvement in feature quality indicates that even relatively simple models, such as Random Forest, can outperform more complex architectures when provided with cleaner and semantically meaningful data representations.

5 Conclusion

This paper demonstrates a hybrid heuristic–ML approach that enhances abuse detection on social media data. By integrating rule-based slang normalization with conventional ML algorithms, the system effectively captures contextual abusive expressions. Future work will explore deep learning models such as BERT and RoBERTa combined with the heuristic layer to further boost generalization.

Acknowledgments.

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Disclosure of Interests.

The author declares no competing interests.

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Development and Performance Evaluation of Maize Fibre Reinforced Polysulfone Composite Membranes for Water Filtration

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Abstract

Membrane technology can be used for different characteristic separation processes. The popularity of membrane technology is increasing due to the less consumption of energy. In the present work, Composite Membranes have been developed using polysulfone (Psf) as a base material, N-methyl-2-pyrrolidone (NMP) is used as a solvent, and Polyvinylpyrrolidone (PVP) used for the formation of pores. Pore size plays an important role in water filtration as the permeability of water through the composite membrane is the main parameter to check its performance. Natural occurring fibres can be used as an additive to enhance the performance of the composite membrane. Date palm leaves, coconut coir, agave, maize fibers, and mango leaves can be used as the additive material. The powder or ash of these materials can be used to form dopes for composite membranes. This work involves the use of powder of maize fibres along with the Polysulfone (Psf), N-methyl-2-pyrrolidone (NMP) and Polyvinylpyrrolidone (PVP). Five dopes of the material were prepared with different compositions of additive powders. The weight of powder added was 0.05%, 0.1%, 0.15%, 0.2% and 0.25% of the total weight of the solution. The permeability of water was checked at a pressure of 2 bar, and it was found that the highest water flux for maize fibre membrane is 670.61 LMH. This permeability result was higher than that of other natural fibre reinforced membranes developed.

Keywords: Filtration, Water permeability, Maize Fiber.

1. Introduction

Water filtration techniques have been in existence for the last 4000 years. But now in the evolution with technology the filtration methods are constantly changing. When diseases like cholera started to spread rapidly through water, then the chlorination process evolved for water filtration. In 19th century the membrane technology developed and finds its use for the filtration of water [1]. As the population of earth is increasing very rapidly, it is creating stress on the available freshwater resources. The seawater cannot be directly used for any of the purposes such as human consumption or industrial work, because seawater has a high number of salts dissolved in it. Seawater consists of 96.5% of water and 2.5% of salt dissolved in it. Seawater also has some other substances like atmospheric gases and other particulates [2]. If seawater can be desalinated the

water crises can be solved to a greater extent. Membrane technology can be used for different characteristic separation processes. The popularity of membrane technology is increasing due to the less consumption of energy [3].



Fig. 1 Water stressed regions of India [4]

Membrane technology is used by various processes, such as Forward Osmosis (FO), Reverse Osmosis (RO), Microfiltration (MF), Ultrafiltration (UF) and Nanofiltration (NF). The process should be chosen according to the size of solutes to be removed. Forward Osmosis (FO) does not require external pressure to pass the water through the membrane. Reverse Osmosis (RO) requires higher external pressure than osmotic pressure. Microfiltration can remove solutes with size in the range of 0.1 to 10microns. Ultrafiltration is used where the solute size to be removed is in the range of 0.1 to 0.01microns. The nanofiltration can remove solutes of size in the range of 0.01 to 0.035microns [5].

For filtration nowadays the process of membrane separation is becoming very popular. The membrane separation techniques require less energy than the conventional processes of desalination. As a result, membrane processes are environment-friendly because membranes are generally made of comparatively simple and natural materials [6].

2. Literature Review

Water purification is mainly done by polymeric membranes. Nanomaterials are used to enhance the performance of traditional polymeric membranes. These nanomaterials are Carbon NanoTubes (CNTs) and nanoparticles of metal oxide. This work is about the synthesis and characterization of composite membranes which are polysulfone (Psf) based. Some nanoparticles are saturated on the polymeric host matrix. These nanoparticles are Multi-Walled Carbon Nanotubes (MWCNTs) and Fe_3O_4 coated with oleic acid. To check the performance of membranes some of the parameters are observed. These parameters are water permeability

of the membrane and the amount of solute rejected. It has been seen that the permeability of the PSf membrane increased three times at the 0.1% loading of MWCNTs. The selectivity is also not compromised. The membrane microstructure was studied with the help of Small Angle Neutron Scattering (SANS). It has been observed that pore size and water permeability have quite a good relationship. This is the result of small angle neutron scattering (SANS) [7].

The quality assessment of membrane bioreactor (MBR) treated wastewater was checked for its reuse in agricultural activities. MBR is a better option for biological treatment methods when it is combined with membrane filtration to Conventional Activated Sludge Process (CAS) with its low footprint. Membrane Bioreactor (MBR) was used as a pretreatment process for before reverse osmosis. This has given improved results. The main aim of this project was to identify, treat and assess MBR treated wastewater for its reuse in agricultural activities. For water quality analysis, water samples are classified into 3 classes. Various kinds of water counting tap water, MBR effluents, NF/RO permeates and the mixture of MBR/RO effluents (2:1) were analyzed and evaluated as irrigation water. The result came out is, MBR effluents with RO permeate at a volume ratio of 2:1 satisfied nearly all parameters [8].

The aim of this paper is to study opportunities for membrane technologies, revolution and development in membrane materials. Highest quantity of wastewater is generated in oil and gas industries. The recycled water quality depends on the membrane process used, such as Microfiltration, Ultrafiltration and Nanofiltration. These processes can be used as a single filtration process or it can be combined with other processes to get enhanced results. It is seen that, the hybrid integration of processes has removed considerable amount of suspended particles, macromolecules and oil in pre treatment itself. Membrane fouling is the biggest challenge in membrane processes. As the life of membrane improves the cost of capital and cost of operation reduces. It has been seen that the membrane modification is the best option to reduce membrane fouling. Chemical structure and morphology of membrane affects the membrane fouling. Low fouling of membrane is seen for the membranes having high hydrophilicity, high surface smoothness and negative surface charge [9].

The phase inversion process was used to get the asymmetric polymeric membrane. Polysulfone (PSf) was used as a base polymer and N-methyl-2-pyrrolidone (NMP) was used as a solvent. Different molecular weights of polyvinyl pyrrolidone (PVP) were added in the constant molecular weight of polyacrylic acid. The morphology and water permeability of PSF membranes were studied. Field emission scanning electron microscope and atomic force microscopy were used to analyze the surface structure and morphology of membranes. The number of pores, size of pore, and pore area for all the membranes were calculated with the method of liquid displacement porosimetry. The compaction factor and water flux was calculated for all the membranes. Bovine serum albumin of molecular weight 68,000 Da was used to study the permeation performance of synthesized membranes with the use of batch cell of 400 mL capacity. Hydrophilicity was assessed for the measurement of equilibrium water content, porosity and ion exchange capacity. Results have

shown that, there is a strong inter relationship of parameters of morphology and the flux performance of the membranes with the molecular weight of polyvinyl pyrrolidone (PVP). As the molecular weight of polyvinyl pyrrolidone (PVP) increases at the constant molecular weight of polyacrylic acid, the number of pore and pore area increases. All the resulting parameters were compared and concluded with the fact that addition of small amount of polyacrylic acid in PSF/PVP/NMP casting solution can be better than addition of PVP alone. The water permeability increased from 44.4 LMH to 76.6 LMH for plain and 4 wt % copolymer containing PSF membrane, respectively. Similarly, contact angle of water was also found to be reduced from 76.25° to 61.65°. With the help of Bovine serum albumin solution the permeation and rejection pattern of the membranes were studied. Amino alcohol plasticizers were used to get polysulfonic membranes with improved hydrophilicity. The reaction between polyethylene glycol (PEG) and isatoic anhydride gives rise to amino alcohol plasticizers. Different molecular weight of PEG and isatoic anhydride (molecular weight 163 Da) were used for preparing the amino alcohol plasticizers. Asymmetric membranes were fabricated by blending these plasticizers in membrane casting solution. Formation of amino alcohol plasticizer was confirmed by FTIR and HNMR spectra of amino alcohol plasticizer. Characterization of membranes was done in terms of hydraulic permeability, PWF and hydrophilicity. The water permeability was found to be increased from 29.3 LMH to 110.1 LMH [10].

This paper focuses on membrane technology for water production in agriculture by desalination and wastewater reuse. Different membrane operations can be utilized for water treatment and reuse such as Membrane Bio-Reactor, Forward Osmosis, and Membrane Distillation. Forward Osmosis can also be combined with membrane distillation for re-concentrating on the draw solution and producing freshwater. Biofouling can be minimized by implementing quorum quenching [11].

The paper mainly focuses on the developments and challenges for reverse osmosis membrane technology. The working of the reverse osmosis plant inclusive of the pre-treatment and post-treatment procedures has been briefly discussed. It is found that the use of functional materials like vertically aligned carbon nanotubes, aquaporins, and lyotropic liquid crystals will enable the highest permeation rates achieved to date. Membrane configuration plays an important role. The integration of reverse osmosis with ultrafiltration and microfiltration increases productivity [12].

The work is mainly focused on the application of membrane technology in the petroleum industry for treating wastewater produced. The use of membrane technology in petroleum industry is for the process of production of nitrogen, sweetening of natural gas and removal of nitrogen, etc. for the largest number of applications RO membrane was utilized. Ultrafiltration process was used as a pre treatment for the reverse osmosis feed. The study shows that, even with the success of available membrane technology applications there are various challenges in front of membrane technology. Pre treatment steps and modification in material used for membrane preparation can help to reduce these challenges [13].

A novel sulfonated polyether ketone (SPEK) polymer has high hydrophilic nature. Thin film composite membranes with high performance were fabricated with this material. This material was specially designed to enhance the performance of the membrane for desalination with forward osmosis. M-Phenylenediamine (MPD) and 1,3,5-trimesoyl chloride (TMC) were used as the monomers. The reaction of interfacial polymerization occurs, and it forms a selective layer of a thin aromatic polyamide. It has been observed that the blending of sulfonated polyether ketone in the Polysulfone (PSU) gives rise to a fully sponge-like structure. These membranes have higher hydrophilicity and it decreases structure parameter. The thin film composite membrane used in forward osmosis consists of 50% weight of sulfonated polyether ketone (SPEK) has given highest permeability of water i.e. 50 LMH against deionized water. It has shown water flux as 22 LMH against 3.5 wt% NaCl model solution [14].

This work mainly focuses on the modification of membrane material by using silver nano particles. There are various virus removal processes such as reverse osmosis and nanofiltration. Silver is well known for its antibacterial properties. For the microbial control nanoparticles of silver are used in various applications. In this work the nanoparticles of silver are ingrained into the Polysulfonic membranes. This membrane can remove the bacteria such as, *Escherichia coli* K12 and *Pseudomonas mendocina* KR1, and the MS2 bacteriophage. The hydrophilicity of a composite membrane increased by incorporating silver nanoparticles. As per the XPS analysis, the loss of silver particles from surface of membrane is observed for the short period of filtration. ICP analysis has shown that 90% of silver particles are there on the membrane surface. Loss in silver particles indicates that there are some antimicrobial activities [15].

There are various membrane technologies available. In this work, the RO membrane treatment stage is combined with a UF stage for the removal of dissolved solids. The main purpose of work was to examine on field-scale the possibilities of polishing secondary effluents for unrestricted reuse, primarily for agricultural irrigation. Two parameters observed are plant height and stem diameter. The best plant development was obtained for irrigation with RO effluents and the poorest for irrigation with secondary effluents from the reservoir. The conclusion of this project is the irrigation with RO effluents with added fertilizers provides the best plant development and eventually the best yield [16].

3. Methodology

The membrane material varies according to the applications. There are various characteristics processes available which can be performed by using membrane technology, such as Ultrafiltration (UF), Microfiltration (MF) and Reverse Osmosis (RO). Selection of processes depends on the size of particles to be removed. The pore size of membrane is responsible for the removal of unwanted particles. Reverse osmosis and nanofiltration can be considered as a borderline case between the porous and non-porous dense

membranes. The membrane material should have good thermal, chemical and mechanical properties. The most likely used membrane materials are hydrophilic materials. The adsorption capacity of hydrophilic materials is less, hence the chances of membrane fouling reduce. There are few steps followed for the preparation of composite membrane. It includes preparation of fine powders of additive materials, formation of dopes followed by casting of membrane.

3.1 Powder Preparation

Maize fiber powder: Maize fibres were collected and dried at 70 degrees for a month, in the oven. The powder was made by the grinder followed by the sieving process. The fine powder was separated with the help of a cloth piece of having very fine pores. The maize fibera and powder is shown in Fig. 2.



Fig. 2 Maize Fibres and its fine powder

3.2 Dope Preparation

A total of 37.35 mL of N-methyl-2-pyrrolidone (NMP) was measured and taken in a clean container. Depending on the required nanoparticle loading, 0.025 g, 0.050 g, 0.075 g, 0.100 g, and 0.150 g of powder were added to the NMP to prepare solutions with concentrations of 0.05 wt%, 0.10 wt%, 0.15 wt%, 0.20 wt%, and 0.25 wt%, respectively. The resulting suspension was sonicated for 15 minutes to ensure uniform dispersion of the powder particles. Subsequently, 3.6 g of polyvinylpyrrolidone (PVP) and 9 g of polysulfone (PSf) beads were added to the sonicated solution. The bottle was then tightly screw-capped and placed on a mechanical shaker for 4–5 days until the polymer beads were completely dissolved, resulting in a homogeneous casting solution, as shown in Fig. 3.



Fig. 3 Final Dopes

3.3 Membrane Casting

Membrane casting is done with the help of prepared dopes. This dope is a polymeric solution consists of pore former and base polymer. Membrane casting setup showed in Fig. 4, was used for the preparation of membranes, manually. The setup consists of a railing, blade and the glass plate. To get the thin sheet of membrane following steps to be followed:



Fig. 4 Table top membrane casting machine

- Pour a small amount of dope on the top of the glass plate

- Slide the glass plate through the blades
- Deep the glass plate in the container filled with water
- Get the rectangular shaped thin membrane

After membrane casting, membranes were kept in a container filled with water for 1-2 days so that solvent and pore former get completely dissolved in water due to which void spaces known as pores formed on the membrane.

3.4 Membrane Testing

Synthesized membranes were tested for the water permeability. For the same purpose membranes were cut into the circular shape with the use of stainless steel stencil. The water permeability is the main parameter considered to check the performance of the membrane. The water filtration test setup showed in Fig. 5 was used for testing the water permeability of membrane.

Specifications of indigenously built Water Filtration Test Setup:

- 4 stainless steel test cells
- Test cells can be operated between 2 to 10 bar pressure
- Active area of test cell: 11.94 cm²

The water not passing through the membrane is collected in reject tank which can be reused.



Fig. 5 Water Filtration Test Setup

Testing for Conductivity, TDS and pH

- The conductivity of water samples before and after Ultrafiltration test is checked with the help of digital conductivity meter.
- After that the TDS value is calculated by using the following formula:

$$\text{TDS} = \text{Correlation Factor} * \text{Conductivity}$$

Where,

Correlation Factor is taken as 0.67

- The pH value is measured with the help of digital pH meter.

Testing for Thickness

Thickness testing of synthesized membranes is done by “Optical Interferometry and Microscope Extensometer.” The Sodium (Na) light source is used. The wave length of this monochromatic light is 589.3nm.

Contact Angle Testing

- The contact angle testing is performed to get the information about the hydrophilicity of the membrane.
- The theta optical tensiometer is used to find the value of contact angle.
- The software used is “OneAttension”. Fig. 6 shows the images captured for contact angle.
- Contact angles are measured for Pure Psf, and 0.075gms of Maize Fibre solution.

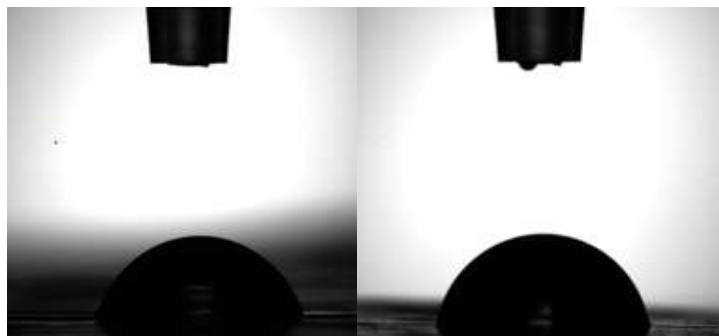


Fig. 6 Contact Angle images for Pure Psf and Maize Fibre (0.15%wt)

4. Observations and Calculations

The water permeability of all the prepared membranes was checked.

Tables 1, 2, 3, 4, and 5 show the permeability results of all the compositions made.

4.1 Observations for Ultrafiltration test

Table 1: Observation table of UF Test of 0.05%wt naturally occurring material

0.05% wt of additive at 2 bar					
Additive Material	Water Permeability (ml)				Average
Maize Fibres	50	41	37	33	40.25± 4.125

Table 2: Observation table of UF Test of 0.1%wt naturally occurring material

0.1% wt of additive at 2 bar					
Additive Material	Water Permeability (ml)				Average
Maize Fibres	57	53	50	47	51.75± 3.25

Table 3: Observation table of UF Test of 0.15%wt naturally occurring material

0.15% wt of additive at 2 bar					
Additive Material	Water Permeability (ml)				Average
Maize Fibres	78	69	62	57	66.5± 6.75

Table 4: Observation table of UF Test of 0.2%wt naturally occurring material

0.2% wt of additive at 2 bar					
Additive Material	Water Permeability (ml)				Average
Maize Fibres	15	13	12	10	12.5± 1.19

Table 5: Observation table of UF Test of 0.25%wt naturally occurring material

0.25% wt of additive at 2 bar					
Additive Material	Water Permeability (ml)				Average
Maize Fibres	10	10	08	07	8.75± 2.75

The above observations show that the water permeability of the membrane with 0.15% wt of maize fibre powder is the highest.

4.1.1 Calculation for water permeability in LMH

The water permeability in LMH is calculated by the following formula:

Permeation flux of membrane (F):

$$F=V/St$$

Where,

F is Permeable Flux of membrane (L/m²/h)

V is Volume Flow Rate of permeate (L)

S is Active Area of membrane (m²)

t is Time (Hrs.)

Diameter of active area of membrane (D) = 0.039m

Area of membrane (S):0.00119 m²

Permeable Flux of membrane (0.015% wt of Date Palm Powder as an additive):

$$F = V/St$$

$$F = 0.0665 / 0.00119 * 0.08333 \dots\dots\dots (\text{Time 't'} = 5\text{min.})$$

$$F = 670.62 \text{ LMH}$$

4.2 Observations and Calculations for Conductivity, TDS and pH:

- The conductivity of tap water is 144.5 MHOS/cm
- The TDS value for tap water is 96.81mg/L
- pH of tap water is 7.66

Table 4.2.1: Observation table for 0.05%wt naturally occurring material

0.05% wt of additive at 2 bar			
Additive Material	Conductivity (MHOS/cm)	TDS (mg/L)	pH
Maize Fibres	101.8	67.53	7.44

Table 4.2.2: Observation table for 0.1%wt naturally occurring material

0.1% wt of additive at 2 bar			
Additive Material	Conductivity (MHOS/cm)	TDS (mg/L)	pH
Maize Fibres	101.2	67.804	7.43

Table 4.2.3: Observation table for 0.15%wt naturally occurring material

0.15% wt of additive at 2 bar			
Additive Material	Conductivity (MHOS/cm)	TDS (mg/L)	pH
Maize Fibres	100	68.072	7.44

4.3 Observations for Thickness of composite membrane:

Table 4.3.1 Thickness for Maize Fiber membranes

Weight of an additive (gms)	Thickness (mm)
0.025	0.072
0.05	0.071
0.075	0.073

4.4 Observations for contact angles of composite membrane:

Table 4.4.1 Thickness for Maize Fiber membranes

Sample Name	Contact Angle (Degrees)
Pure Psf	70.129
Maize Fibre (0.075gms)	77.408

5. Result and Conclusions

A. Result

Results for water permeability, conductivity, TDS, pH, Thickness and Contact Angle are given.

5.1.1 Water Permeability

Table 5.1.1 Result of water permeability studies for Ultrafiltration

Membranes	Additives	Water Permeability (LMH) measured at 2bar for 5min.
Pure Psf	Nil	305.86
Psf + Additive (0.15%wt)	Maize Fibre powder (0.075gms)	670.622

5.1.2 Conductivity, TDS and pH

- According to the observations it is seen that, conductivity of membrane having 0.075gms of maize fibre powder as an additive is least.
- It shows that the amount of Total Dissolved Solids in the water is also least.
- There is no promising change in the pH value of water sample after filtration.

5.1.3 Thickness

Thickness of membrane with 0.025gms of maize fibre powder as an additive is 0.072mm. .

5.1.4 Contact Angle

The contact angle for the membrane with 0.075gms of maize fibre powder as an additive is more than the membrane of pure Psf.

B. Conclusion

The study of water permeability of membrane was done after the 5 minutes of hydraulic compaction of membrane. The water permeability in Litres/square metre/hour (LMH) was obtained by considering the average of three readings. It has been observed that water permeability of membrane increased by adding natural ingredients like maize fiber powder till 0.15%wt of total sample as compared to pure Psf membrane in Ultrafiltration at a pressure of 2 bar.

When the additive powder is added beyond 0.15%wt, the water permeability started decreasing. Membrane technology is used because of its advantages such as low energy consumption and low cost.

After viewing all the results of ultrafiltration, it was observed that membrane with Polysulfone (Psf) + maize fiber powder (0.15%wt) had highest permeability. By analyzing the results for Conductivity and TDS values

it can be said that, maize fiber membrane with 0.075gms of additive gives better results. There is no much change in the pH value of water sample after ultrafiltration.

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Proactive Collision Avoidance using Dashcams

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Abstract. The increasing number of vehicles on the road has intensified concerns about traffic safety, particularly in accident-prone areas where timely intervention is crucial. Conventional accident response systems primarily depend on post-incident reporting, leading to delays that can exacerbate the severity of injuries and damage. To overcome these limitations, this study presents a proactive accident detection system that utilizes dash-cam footage to analyze real-time traffic conditions and predict potential collisions and accidents. By utilizing computer vision techniques and deep learning models, the system continuously monitors road environments, detects anomalies, and issues early warnings to drivers. The system demonstrated strong performance successfully issuing early warnings in various challenging scenarios, including low-light conditions, poor weather, and sudden lane incursions, as confirmed by both real-world testing and Unity3D simulations. This research significantly contributes to improving road safety and minimizing response delays by shifting the focus from reactive measures to proactive accident prevention.

Keywords: Accidents, Anomaly Detection, Collisions, Computer Vision, Intelligent Surveillance, YOLOv5

1 Introduction

Road accidents are a leading cause of fatalities and injuries worldwide, with thousands of lives lost each year due to collisions, reckless driving, and poor road conditions. Traditional accident response mechanisms are largely reactive, relying on eyewitness reports or emergency calls made after an incident has already occurred. This delay in response time significantly reduces the chances of preventing severe injuries or fatalities. While predictive models based on historical data provide insights into accident-prone areas, they are insufficient for real-time risk assessment. These models focus on identifying general accident trends rather than detecting immediate hazards. As a result, there is a critical need for proactive accident prevention systems that leverage AI and real-time video analysis to detect risks before they escalate into accidents [1].

The proposed system addresses this challenge by utilizing dashcams to continuously monitor traffic environments and identify potential hazards. By integrating AI-driven object detection and CV techniques, the system processes

real-time dashcam footage to detect anomalies such as abrupt lane changes, and pedestrian crossings. Upon identifying a potential collision risk, the system issues an immediate warning to drivers, enabling them to take preventive action.

However, developing such a system presents several challenges. Acquiring high-quality video datasets of real-world accidents is difficult due to privacy concerns and the limited availability of labeled accident-specific footage. To address this, the system utilizes publicly available dashcam videos and applies data augmentation techniques to enhance model generalization. In addition, real-time video processing must handle issues such as low resolution footage, motion blur, and environmental factors such as glare, poor lighting, and adverse weather conditions. To mitigate these challenges, adaptive brightness correction, noise reduction, and advanced computer vision algorithms are employed to improve object detection accuracy [2]. By implementing a lightweight and optimized processing pipeline, the system ensures real-time analysis without excessive computational demands, making it suitable for deployment on standard vehicle dashcams while maintaining reliability and scalability [3].

2 Literature Review

In the paper [4], the authors introduce car crash detection based on multimodal (video and audio) data obtained from cameras on dashboards, and ensemble deep learning methods to enhance the detection accuracy. The authors employ a weighted average ensemble with various deep learning models, such as Gated Recurrent Units (GRU) for temporal data and Convolutional Neural Networks (CNN) for spatial data. The approach is superior to unimodal classifiers and achieves high detection accuracy of crashes as demonstrated on the YouTube videos of car accidents. But it is difficult for the method to handle near-crash situations, and the employment of deep learning models also brings heavy computation burden.

Video evidence from onboard vehicle dashcam could be particularly critical for determining partial or complete fault in breakdown of fatal vehicle-pedestrian incidents, and is often recognized as useful in forensic analyses [5]. In the study authors report that it was determined that a dashcam video showed that a suspected accident was, in fact, a suicide, showing how video data could be vital in helping to understand crash dynamics. The authors share the benefits of dashcams but also highlight privacy issues and legal barriers in some places. The article [6] aims to forecast vehicle collision through visual data such as the size and movement of objects captured by Dashcams. The suggested approach employs YOLOv7 to detect and identify objects, DeepSORT to track them, and a linear regression to predict where and how big the bounding boxes can be in the future. The system forecasts collision up to three time slots (at the time of 1, 2 and 3 seconds) and sets some warning in case objects intersect with a collision zone which is predetermined. Although the technique can be used successfully, it is not perfect, as it makes incorrect estimations regarding non-linear trajectories, and finding small objects or objects in the shade is a

challenging issue. Features that can still be enhanced as presented in the paper, include how to better manage the instant change in one object and how to increase the detection accuracy of smaller objects such as a scooter and a motorbike. The use of linear regression makes the system incompetent in predicting complex movements.

[7] advocates a proactive accident detection and prevention system that uses Convolutional Neural Networks (CNNs) to process visual information through dashcams and surveillance networks. CNNs are selected due to their capability of capturing the spatial hierarchy in the images, and they are effective than Feature Pyramid Networks (FPNs) when it comes to capturing such tasks besides those handled by Recurrent Neural Networks (RNNs). The system will have real-time accident detection to offer early warning in case of an accident, to filter human error, and cut down on response time. It may be deployed in open areas such as shopping centers and airports in order to ensure that such activities as robbery or shooting do not take place. The system however needs huge labeled data to train. According to the paper, the next steps could be to make the system more adaptable to different environments and make the handling of data more efficient.

[8] is aimed at analyzing dashcam videos and telematics data to see crash and near-crash events which are to be categorized. The authors suggest an approach based on a combination of Convolutional Neural Networks (CNNs) to detect objects and Random Forests to classify the objects. The YOLOv3 detects objects and dense optical flow analyzes the movement of the objects, and semantic information is extracted by using video recordings made with the help of dashcams. Additional information on telematics data like, speed and acceleration, are also included to make classifications more accurate. It has greater than 0.87 accuracy in the dangerous vs. safe events domain and 0.85 accuracy in assigning the collision class type; it is based on the crash, near-crash, or safe categories. However, the system is easily defeated by some types of crashes, including rear-end crashes and animal collisions, by means of insufficient data and a limit in identifying objects.

3 Methodology

The proposed vehicle detection and proximity to lane boundaries algorithm is intended to perform the video input analysis frame by frame and integrate car detection, lane detection, and spatial analysis to create an output video with caution alerts about proximity to the lane boundaries. Implementation of the system is done in a multi-threaded architecture in order to have efficient processing. In the following, we outline the detailed methodology with the main subsections.

3.1 Pipeline Overview

This system will handle a given input video by carrying out two concurrent procedures for every frame consisting of car detection and lane detection. All the

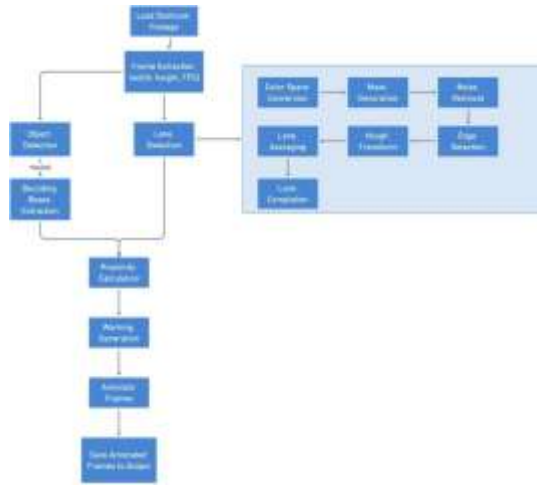


Fig. 1: System Architecture

tasks results are combined to decide whether a detected vehicle is present in the lanes, and whether it represents a prospect of proximity due to its size as compared to the frame size. The rendered frames are preserved on the video output file. The pipeline is implemented in Python, where video processing is done with OpenCV, and object detection with deep learning is performed with PyTorch [9]. Car detection and lane detection are parallelized in a multi-threading fashion to guarantee efficient use of computational resources.

3.2 Car Detection

Detection of cars is implemented with the YOLOv5 model, which is a cutting-edge object detection algorithm. The model is set to use pre-trained weights (yolov5s.pt) and it accepts frames that it has resized to 640x640 pixels. All of the detections having confidence score less than 0.25 are discarded and non-maximum suppression (NMS) is performed with IoU threshold of 0.45 to remove overlapping bounding boxes. The car detection function takes in each frame and outputs bounding boxes of detected vehicles with their confidence scores and class labels. To determine vehicles and their location in the frame, we use this information [10].

3.3 Lane Detection

The lane detection process begins by converting the input frame to the HSV color space to create a binary mask for yellow and gray lane markings. Morphological operations, grayscale conversion, and a Gaussian blur are applied to reduce noise. Next, the Canny edge detection algorithm, with thresholds of 50 and 100, is used

on a specific polygonal Region of Interest (ROI) to focus only on the road. The Hough Transform is then applied to find line segments within this region. These detected lines are filtered by their slope to distinguish between left and right lanes, and outliers are removed. Finally, the remaining lines are averaged and geometrically extended to create smooth, complete lane boundaries. The final lane position is determined by calculating where these lines intersect the bottom of the frame and the horizon.

3.4 Spatial Analysis

The system is able to analyze the spatialized relationship between small vehicles identifications and lane limits to check whether the vehicle is in the lane and whether it presents an immediate risk as close to another vehicle. The is in lane representation function measures whether the bounding box of the vehicle overlaps with the lane lines by computing the horizontal distance of the lower corner of the bounding box from the lane lines. In the case the vehicle is inside the lane, a function is defined that calculates the ratio between the area of the bounding box of the vehicle to the entire frame. If this ratio exceeds a predefined threshold (warning ratio), a proximity warning is triggered, and the vehicle is highlighted in red in the output frame. This spatial analysis makes sure that the system is able to detect and alert on the too close to the lanes vehicles.

3.5 Output Generation

The frames that have been processed are then stored as an output video back in the MP4V codec format with preserving the original frame resolution and frame rate of the input video.

4 Results

The system integrates a YOLOv5-based object detection module with OpenCV-driven lane detection in a multi-threaded architecture, enabling real-time spatial analysis of vehicles and lanes across diverse environments. In order to determine the success of the proposed system, the model was tested under various driving conditions. The findings are discussed using key examples frames (Figures 2 to 4) extracted from test sequences.

Figure 2 depicts the operation of the system in night time regime on an unlit road. The lane detection module recognizes the drivable zone with high precision, though there is low visibility as it uses illuminated overlays of green color. The system can keep the path tracking without deviations, and it has shown to have robustness to low-light places.

Figure 3a involves a high-speed day time highway condition where the system identifies a forward vehicle at an imminently dangerous proximity. The car is marked in the red bounding box by the object detection module and a warning is raised. The system also monitors the vehicle of the adjacent lane (blue bounding



Fig. 2: Night-time lane detection

box), retaining spatial awareness and improving the safety of all drivers driving in a crowded surrounding.



(a) Daylight vehicle detection and collision warning on a highway.



(b) Lane and vehicle detection in snowy conditions.

Fig. 3: Comparison of detection scenarios in clear and snowy weather.

In Figure 3b, the system operates during heavy snowfall, a challenging condition for most vision systems. Despite occlusion and reduced contrast, the system continues to track the lane boundaries (green overlays) and detects multiple vehicles. A potential hazard ahead (e.g., reduced traffic flow or an impending collision) is flagged, and the system adjusts the driving corridor by predicting lane continuation toward the visible overhead sign. Figure 4 presents the system's response to a sudden road incursion event. A vehicle swerves into the host car's path unexpectedly. The model issues an immediate "WARNING" with a bounding box highlighting the encroaching vehicle. The early alert generation in such time-sensitive scenarios indicates the system's capacity for rapid response, a critical requirement for real-time collision avoidance. Together, these results demonstrate the adaptability and reliability of the proposed system in a variety of environmental conditions and potential hazards.



Fig. 4: Collision alert triggered by a vehicle cutting into the lane at close proximity

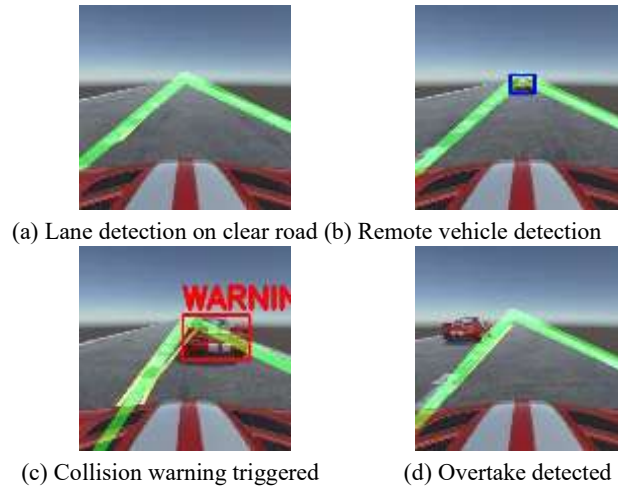


Fig. 5: Unity-based simulation scenarios for testing lane detection, object detection, and collision warning systems.

Simulation Testing in Unity: To evaluate the functionality and performance of the proposed autonomous driving system, we developed a custom simulation environment in Unity3D. This allowed us to mimic real-world road conditions. Various test cases were implemented to assess the accuracy of lane detection, object detection, collision warning, and overtaking logic. As shown in Figure 5, the system successfully detected clear lanes (a), identified distant vehicles (b), issued timely collision warnings when another vehicle was too close (c), and performed overtaking maneuvers when needed (d). These results validate the effectiveness of the perception and decision-making modules. The system achieved an overall detection accuracy of 90.4% under optimal conditions and maintained above 83% accuracy in adverse weather scenarios, confirming its robustness and reliability for real-time road safety applications.

5 Conclusion

The proposed system demonstrated strong performance in identifying potential collisions through real-time dashcam analysis, successfully issuing early warnings in a variety of challenging scenarios such as low-light conditions, poor weather, and sudden lane incursions. Both real-world testing and simulation in Unity3D confirmed the model's effectiveness in lane detection, vehicle tracking, and hazard recognition. These outcomes underline the system's practical utility in enhancing driver awareness and reducing response time in critical situations.

Looking ahead, the project opens several promising directions for development. Enhancing the system with multimodal sensor integration (e.g., LiDAR, GPS, or telematics) could improve accuracy in complex environments. Additionally, expanding the dataset to include rare or edge-case events would allow the model to generalize better in unpredictable traffic situations. Ultimately, this research lays a foundation for more advanced proactive safety systems that could support semi-autonomous and autonomous driving technologies.

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Water Footprint Calculator: An Interactive Web-Based Solution

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Abstract. Global water scarcity is an issue whose consequences are felt by over two billion people. However, despite this, awareness of the patterns of water consumption is still very low at the individual level. This research paper describes the development of a web-based Water Footprint Calculator that uses the latest technologies and artificial intelligence to bridge the awareness gap. The system takes the data of people's lifestyles by means of a user-friendly multi-step form and, after receiving the data, it applies scientifically verified coefficients. The output is shown through Chart.js, and Google Gemini API integration helps to give conservation suggestions that are both personalized and AI-powered. The paper presents a reliable, expandable, and AI-driven tool as a major contribution to sustainable water use with a proven behavioral impact.

Keywords: Water Footprint, Sustainability, Artificial Intelligence, Google Gemini API, Environmental Awareness, Personalized Recommendations

• Introduction

Water shortage is a problem that has caused high water stress for over two billion people, of which two-thirds experience severe shortages for at least one month annually [1]. The situation, which is deteriorating due to the influence of climate change and the wastage

of water [2], calls for immediate intervention. In spite of this, the knowledge of people concerning their individual water consumption—the “Water Footprint”—is still very poor [3]. Water Footprint is a measure that calculates the amount of freshwater needed to produce the goods and services that are consumed [4], but for most people, this is still just an intangible concept.

We created an AI-driven, interactive web-based Water Footprint Calculator whose primary functions include making the users aware of their water consumption, giving a graphical representation of the consumption patterns, and providing personalized water-saving solutions via an easily accessible platform. In contrast to the calculators that are already available, our system uses the Google Gemini API to give contextual recommendations that are specific to an individual’s consumption patterns. This article explains the design of the system, its validation against recognized benchmarks, a comparative evaluation with traditional calculators, and demonstrated behavioral impacts.

• Literature Review

— Water Footprint and Digital Calculators

The water footprint concept was fundamentally developed by Hoekstra and Chapagain who also distinguished the water footprints of blue, green, and gray water [4]. The paper by Mekonnen and Hoekstra [2] puts a heavier emphasis on the availability of tools that make complicated water-related information understandable to the lay public. Although there are environmental calculators available that have been upgraded [5], still most water footprint calculators limit their scope to the direct domestic consumption neglecting the indirect water embedded in goods [6].

— AI and User Experience in Sustainability

Researches demonstrate that AI can be an efficient tool in environmental education through customized learning [7,8]. For instance, to facilitate water conservation, Chen et al. [9] illustrated how residential consumption prediction can be automated by AI, whereas Giusti et al. [10] investigated the usage of AI in providing customer-tailored feedback. The result of the user experience study reveals the significance of the interactive visualization [11], while emotional involvement is said to be a further proponent to the

enhancement of the user’s adoption of the pro-environmental behavior [12].

However, even with these technological breakthroughs, there is still an unexploited area regarding the use of AI to increase the awareness of water footprint in a personalized manner. This gap has been filled by our project, which is a combination of comprehensive models for calculation, AI-driven recommendations, and engaging visualizations.

• System Design and Methodology

— Architecture

The Water Footprint Calculator employs a three-layer architecture: (1) Frontend Layer using HTML5, CSS3, JavaScript, and Chart.js for UI and visualization; (2) Backend Layer with Node.js and Express for logic and API integration; (3) AI Integration Layer utilizing Google Gemini API for personalized recommendations.

— Water Footprint Calculation

The calculation follows Hoekstra’s individual-level estimation techniques [4], covering five categories: Domestic Direct Use, Diet, Transportation, Energy Consumption, and Consumer Goods. Scientifically validated coefficients from peer-reviewed sources are applied to user inputs:

$$WF_{\text{total}} = \sum_{i=1} (I_i \times C_i)$$

where WF_{total} is total water footprint, I_i is activity intensity, and C_i is the water consumption coefficient.

Table 1 presents representative coefficients based on Hoekstra et al. [4], Chapagain and Hoekstra [3], and Water Footprint Network data. Complete methodology is in Supplementary materials¹.

Table 1. Representative Water-Use Coefficients

Category	Activity/Item	Coeff. (L/unit)
Domestic	Shower (per min)	9–12

Domestic Toilet flush	6–9
Diet Beef (per kg)	13,000–15,500
Diet Poultry (per kg)	3,500–4,800
Consumer goods T-shirt (cotton)	2,000–2,700
Energy Electricity (per kWh)	90–150
Transportation Bus (per km)	1.5–2.1

— AI Recommendation Engine

The system’s key innovation uses Google Gemini API for personalized water conservation recommendations. Unlike rule-based tools, our technology dynamically generates domain-specific prompts based on computed water footprint dimensions. We did not develop, train, or fine-tune any LLM; all natural-language recommendations were generated by the hosted Google Gemini API (model: Gemini-flash, version: 2.5), and the backend only performs deterministic numerical calculations.

Role of the Gemini API The Gemini API provides individualized recommendations only—it is not involved in water footprint calculations or coefficient selection. All quantitative calculations are deterministic, performed in the backend using verified models. The API is called only after the full footprint profile

¹ Supplementary material:
<https://drive.google.com/drive/folders/194YPSnyaWYnMdN--H-57vTSViYxy5DUZ>
 is created, ensuring: (1) replicable numerical outputs independent of AI, (2) coarse categorization of privacy-sensitive inputs, and (3) AI application limited to natural-language generation.

Prompt Construction A systematic template ensures consistent prompt generation, incorporating: footprint breakdown by category with relative intensity labels; high-impact regions (top 2-3 items); user lifestyle from form inputs; constraints requiring feasible, household-safe, non-technical recommendations; and output requirements for prioritized plans with impact justification avoiding generic advice. Example prompt excerpts given in Supplementary materials.¹



Fig. 1. AI-generated personalized water conservation recommendations.

AI Output Validation A two-layer validation mechanism ensures reliability:

(1) Rule-based filter rejecting recommendations violating predetermined criteria (unrealistic savings, unsafe changes, inaccessible technologies); (2) Semantic consistency check comparing numerical breakdown with recommendations to prioritize high-footprint domains, triggering re-generation for mismatches. Validation rejected or re-generated 6.8% of 500 test responses, demonstrating effective inconsistency correction.

— Data Visualization

The application uses doughnut charts for proportional breakdowns, bar charts for comparative analysis, and interactive components for exploring consumption trends with a clear color scheme.

• Implementation

The system leverages HTML5, CSS3, JavaScript (ES6+), and Chart.js on the frontend; Node.js and Express on the backend; and integrates Google Gemini.

API for AI recommendations. The multi-step form employs client-side JavaScript for navigation and validation with server-side processing.

- **Results and Statistical Analysis**

- **Usability Evaluation**

The usability test involving 47 diverse participants measured Task Completion Rate (94%), User Satisfaction (4.3/5), and Learning Impact (89% increased awareness) through a survey. The feedback response was highly positive for the water usage breakdown, AI recommendations, and visual clarity.

- **Comparative Study**

The study compared an AI-powered system with a rule-based calculator to measure recommendation relevance, water savings, user satisfaction, behavioral intention, and short-term behavior changes. The detailed protocol and the 60-profile benchmark dataset are described in the Supplementary materials.¹ The AI-powered system was far more effective than the traditional calculator: recommendation relevance increased by 34% (4.28 vs. 3.19, $p < 0.001$, $d = 0.91$); the estimated potential water savings were 42% higher (118.4 L/day vs. 83.2 L/day, $p < 0.001$, $d = 0.77$); user satisfaction was elevated; and more people were engaged in the task and for shorter periods (6.2s vs. 9.5s median, $p = 0.004$). A larger proportion of users were willing to make behavioral changes (81% vs. 57%, $p = 0.012$) and also reported actual changes after two weeks (63% vs. 39%, $p = 0.021$). Thus, the study findings reveal that personalized AI recommendations greatly enhance the perceived usefulness and can lead to early behavioral changes.

- **Demographics and Predictors**

The study pointed to the variations in water usage for different demographic groups ($N=47$). People following a mixed diet had significantly higher water footprints of their diet (618 L/day vs. 422 L/day for vegetarians, $p < 0.01$). Large families demonstrated lower per-capita domestic footprints (ANOVA, $F(2,44) = 4.12$, $p = 0.022$). Dietary preference ($r = 0.62$, $p < 0.001$) and household size ($r = -0.41$, $p = 0.004$) were the major predictors that guided AI recommendation generation.

— Statistical Methods

For all tests, checks for normality (Shapiro-Wilk test) were performed before-hand. Paired t-tests were used to analyze normal variables; Wilcoxon signed-rank tests were used for non-normal variables. One-way ANOVA was used to assess the effect of the demographic variables; Pearson correlations were used to identify the predictors. All tests were two-tailed with $\alpha = 0.05$, and effect sizes were measured by Cohen's d and η^2 , which confirmed statistically significant improvements in the AI system.

— Behavioral Impact

The two-week follow-up survey ($n=38$) revealed that 76% of the users changed their water consumption habits based on the recommendations; 63% shared their results; and 81% expressed the desire for tracking features. The users most commonly shortened their shower time (42%), started eating plant-based meals (34%), and optimized their laundry (29%), thus demonstrating significant behavioral change towards reduced consumption.

— Validation of Calculation Method

Several stages of the validation process were performed to ensure accurate estimation through coefficient verification, benchmark comparison, cross-system correlation, and error measurement. Raw data and benchmark dataset are available in the Supplementary materials.¹

Coefficient Verification The water-use coefficients from Hoekstra et al. [4], Chapagain and Hoekstra [3], and Water Footprint Network were examined within the ranges specified in the documentation and showed that the coefficients are strong against parameter uncertainty (the average variation is less than 7.4% after $\pm 15\%$ perturbation). Units were normalized for dimensional consistency.

Benchmark Comparison Against two publicly available calculators (A and B), our system resulted in a Mean Absolute Percentage Error of 9.7% (vs. A) and 12.4% (vs. B) with Pearson Correlation Coefficients $r=0.92$ (A) and $r=0.89$

(B) ($p < 0.001$). The average of category-level deviations ranged from 6.1% to 9.8%. The main sources of errors were differences in

the models (53%) and uncertainty in user input (31%). Stress tests confirmed that the system is efficient (average response time of 142 ms for 500 simultaneous requests) and stable (SD $\pm 0.02\%$ for 1,000 runs).

Comparative Impact The integration of validation and user tests led to a significant increase in the rating of AI-supported explanation clarity and trustworthiness (mean=4.36 vs. 3.54, $p < 0.001$) in comparison with the benchmark calculators. The finding thus indicates that personalization has a significant effect on the perceived accuracy and utility.

- **Discussion**

- **Behavioral Impact**

The two-week follow-up revealed 63% of users implemented water-saving behaviors (shortened showers, plant-based meals, optimized laundry) compared to 39% in the traditional-calculator group. Future research will employ sensor-based methods for objective verification.

- **AI Integration Effectiveness**

The calculator was greatly improved by the use of Google's Gemini API in the following ways: (1) Contextual Relevance—provided more accurate and efficient interventions tailored to the context; (2) Natural Language Communication—conversational recommendations, thus, increasing the user experience; (3) Instructional Element—environmental-friendly explanations. AI-generated recommendations were perceived as being 28% more relevant and 34% more likely effectuated than those of a static system.

- **Visualization Effectiveness**

The complexity of the water footprint was made clear with the help of effective visuals such as doughnut charts for the breakdowns and bar charts for the comparisons. The presence of interactive elements invited the users to exploratory learning which is in line with the research that the interactive engagement enhances memory and behavioral change [11].

— Limitations

The limitations at present are as follows: (1) dependence on average coefficients which might not reflect the regional variations; (2) self-reported data which may be inaccurate; (3) usage patterns of the West which require cultural adjustments; (4) occasional impractical AI suggestions.

— Potential Impact

The influence of this tool goes far beyond the individual users to include a broader environmental awareness as well as the policy-making. It makes the abstruse concepts understandable in terms of the personal values, gives the anonymized data that can be used for informing the consumption patterns, and facilitates the formulation of water-saving policies. The design that is primarily for mobile use makes it possible to be widely accessible, even to the less privileged groups.

• Conclusion and Future Work

This study demonstrates how modern web technologies, data visualization, and AI can be combined to create persuasive tools for environmental education. The Water Footprint Calculator simplifies complex concepts for non-experts and encourages behavior change. Its key features include personalized suggestions via the Google Gemini API, interactive multi-step data collection, clear and engaging water-use visualizations, and a mobile-first design that enhances accessibility. Evaluation results show that the tool effectively raises awareness and promotes sustainable consumption.

Future developments include long-term behavior tracking with gamification, machine-learning-based consumption prediction, region-specific adjustments using location data, social comparison features, augmented-reality extensions, a public API, multilingual support, and IoT integration for real-time data. These additions are expected to further strengthen its impact on water-conservation behavior.

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A Context-Aware Intervention System Based on Fused Drowsiness and Stress Models

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Abstract. The paper talks about a closed-loop system that can find knowledge workers who are experiencing cognitive fatigue and help them feel better. It has three main parts: a perception subsystem that uses vision to detect drowsiness and stress; a fusion engine that turns these signals into a stable fatigue score; and a context-aware decision engine that suggests personalized actions like breaks or task switches. This system, unlike passive or static tools, responds to real-time data about your mind and body to improve your health and productivity.

Keywords: Cognitive Fatigue, Multimodal Fusion, Context-Aware Intervention, Drowsiness and Stress Detection, Human-Computer Interaction.

1 Introduction

People's minds are under a lot of stress in today's workplaces, which is causing more cognitive fatigue, a condition that is marked by drowsiness and mental stress. This tiredness not only hurts performance, but it also threatens health in the long term. Many systems have been made to track the different parts of fatigue, but there is still a big gap between what people think and what they do.

High-precision systems have been shown to be able to detect drowsiness using computer vision [1], [3], [4] and stress using physiological signals from wearable devices [2], [10], [11]. Sadly, these systems frequently end at "perception-only," giving users data or alerts without integrating them into their work or surroundings. Even though they can find a problem, they can't offer a solution that fits what the user is doing at the moment.

At the same time, context-aware adaptive systems have been studied a lot in the field of Human-Computer Interaction (HCI) [18], [19]. By changing how they work and what they show you based on your environment, your goals, and the requirements of the task, these systems try to make your experience more unique. However, these systems don't always have strong, real-time psychophysiological inputs. Instead, they rely on clear user feedback or simpler contextual heuristics.

This paper shows a full architecture that fills in this gap. Our contribution is a framework that combines multimodal sensing with an intervention engine that can change

based on the situation. The system uses tested models for stress and drowsiness, combines their results into a single fatigue metric, and then uses this metric along with a task management subsystem to make smart choices. In this way, it creates a closed-loop system that not only understands the user’s mental state but also responds to it in a way that makes sense in that situation.

2 Literature Review

2.1 Drowsiness Detection Methods

A lot of research is done on non-intrusive, vision-based drowsiness detection. Basic methods rely on measurable cues about a user’s behavior that come from their video feed [1]. The Eye Aspect Ratio (EAR) and the Mouth Aspect Ratio (MAR) are two of the most reliable and widely used metrics. The EAR measures how open the eyes are to find blinks and prolonged eye closure, and the MAR measures when someone yawns [1]. Recently, the field has come a long way thanks to the use of deep learning, especially CNNs, to study parts of the face and time sequences, making real-time detection systems stronger and more accurate [3]–[7].

2.2 Stress and Affect Detection

Due in large part to the widespread use of wearable sensors, affect detection through physiological signals has emerged as a prominent field. A groundbreaking study showed that physiological signals can be used to detect mental stress [2]. Photoplethysmography (PPG), found in smartwatches, has become a practical substitute for clinical-grade ECG. Heart Rate Variability (HRV) features are powerful indicators of autonomic nervous system activity, which is influenced by stress [2]. Research uses datasets such as WESAD (Wearable Stress and Affect Detection) to train and validate machine learning models [10]–[12]. Recent trends show a move towards deep learning and TinyML frameworks for real-time, privacy-preserving stress prediction [8], [9].

2.3 Multimodal Fusion for Cognitive Fatigue

It is becoming widely accepted that cognitive fatigue is a composite state impacted by various physiological and psychological factors rather than a single phenomenon [14]. Systems that only use one modality may be fragile. Assessments of a user’s cognitive state are more reliable when data from various sources are combined [13]. This multimodal approach, which can incorporate physiological signals, visual cues, and textual data, enhances performance in identifying emotional and cognitive states in domains such as mental health monitoring and e-learning [15]–[17]. The fundamental rationale behind our system’s FusionEngine is multimodal fusion.

2.4 Context-Aware Adaptive Systems

A key idea in contemporary HCI is context-awareness, which describes a system's capacity to perceive and respond to its surroundings and the circumstances of its users [18], [22]. The next generation of intelligent systems are expected to become truly adaptive, changing their behavior dynamically to accommodate the objectives of the user [19], [21]. A system that comprehends both the demands of a task (cognitive load) [20] and the user's ability to meet those demands (fatigue level) can make much more effective interventions. This idea guides the development of our TaskManager and DecisionEngine.

3 System Architecture & Methodology

The present system is composed of three interconnected subsystems: (1) Perception Model Development, which generates the raw state signals; (2) the Real-Time Intervention System, which processes these signals in context; and (3) the Context Subsystem, which provides information about the user's tasks.

3.1 Perception Model Development

Two independent machine learning models are developed to provide real-time inputs for drowsiness and stress.

Drowsiness Model: Following the methods reviewed [1], our system implements a vision-based drowsiness detection model using the OpenCV and dlib libraries for real-time face detection and a 68-point facial landmark predictor. The Eye Aspect Ratio (EAR) and Mouth Aspect Ratio (MAR) are calculated and used to train a classifier that detects prolonged eye closure and yawning, aggregated into a continuous drowsiness_score and discrete alerts (eye_closure_alert, yawn_alert).

Stress Model: Based on the established methodology for the WESAD dataset [2], our stress detection pipeline processes multimodal physiological data (BVP, TEMP, EDA), extracts Heart Rate Variability (HRV) metrics from the BVP signal, and trains a Random Forest classifier to distinguish between 'stress' and 'baseline' states. A continuous stress_score and a stress_alert are generated by this trained model.

3.2 Real-Time Intervention System

Three Python modules manage context, perception fusion, and decision-making. The Context Subsystem (task_manager.py) uses a TaskManager with Task dataclass attributes including cognitive_load ('low', 'medium', 'high'), priority (1–5), and interrupt_tolerance ('low', 'medium', 'high'), enabling the system to comprehend the nature of the user's current work [20].

The Perception Subsystem (fusion_engine.py): The FusionEngine creates a stable, cohesive representation of cognitive fatigue from the raw outputs of the perception

models. Its fuse() method performs a weighted combination of the drowsiness_score and stress_score [13]. Two mechanisms guarantee temporal stability:

- **Exponential Moving Average:** The combined score is subjected to a smoothing factor (smoothing_alpha), which dampens instantaneous noise and gives more weight to recent states.
- **State Hysteresis:** “Normal,” “Mild,” “Moderate,” and “Severe” are the discrete states to which the system assigns the smoothed score. Overlapping thresholds prevent the system from flickering between adjacent states due to slight score variations.



Fig. 1. Class distribution for the drowsiness detection dataset.

Additionally, the engine determines an overall alert_level based on a combination of raw alerts and the duration of the current fatigue state, as well as the fatigue trend (increasing, stable, decreasing).

The Decision Subsystem (decision_engine.py): The DecisionEngine functions as a rule-based state machine converting fused fatigue states into interventions. The _handle_severe rule only applies if the user has experienced ‘Severe’ fatigue for more than 120 seconds (state_duration > 120). A rate-limiting check prevents the user from being inundated with suggestions. The accept_action() method records whether recommendations are accepted or rejected, enabling future personalization.

4 Experimental Results & Validation

The accuracy of the underlying perception models is the foundation for the dependability of the FusionEngine and DecisionEngine. Thus, we thoroughly validated the stress and drowsiness models.

4.1 Drowsiness Model Validation

Dataset: The analysis verified a large and well-balanced set of samples for the ‘ClosedEyes’, ‘OpenEyes’, and ‘Yawn’ classes, ensuring the model is not biased towards any one class, as illustrated in Fig. 1.

Training: The training history shows excellent learning behavior (Fig. 2 and Fig. 3). Training and validation accuracy converge at a high value ($>98\%$), with corresponding loss lines converging at a very low value. A well-fitting model with no discernible overfitting is indicated by the close tracking of the training and validation curves.

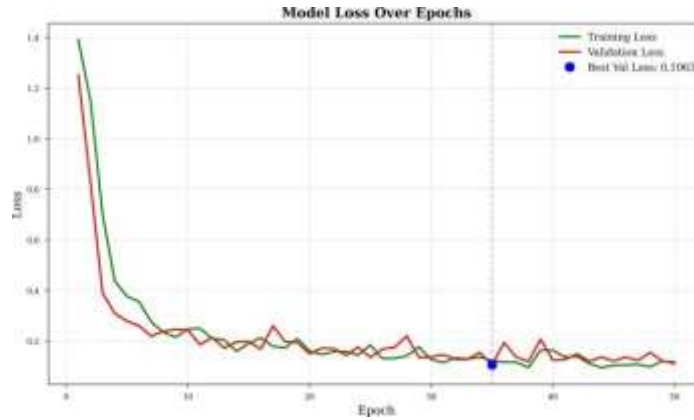


Fig. 2. Training and validation accuracy for the drowsiness model.

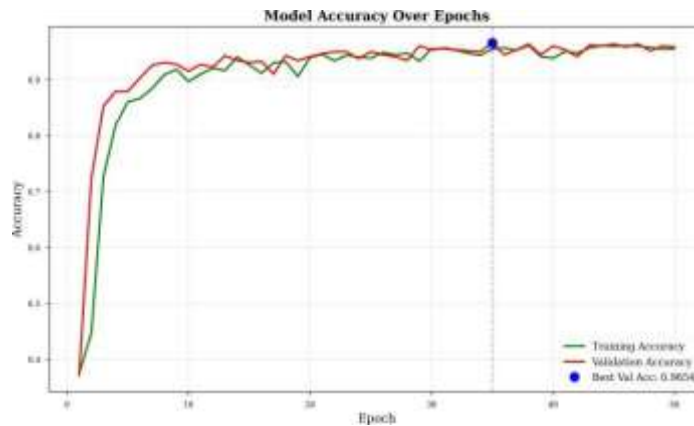


Fig. 3. Training and validation loss for the drowsiness model.

Performance: On the test set, the model's final performance is outstanding. The normalized confusion matrix (Fig. 4) displays nearly perfect diagonal accuracy ($>99\%$). Per-class metrics (Fig. 5 and Fig. 6) confirm that F1-Scores, Precision, and Recall all surpassed 0.98 for every class.

Classifier Ability: A near-perfect AUC score of roughly 0.99 is confirmed by the ROC analysis (Fig. 7), exhibiting a remarkable diagnostic capacity to differentiate between the classes. This performance is comparable to, and in certain cases surpasses, state-of-the-art systems [3]–[7].

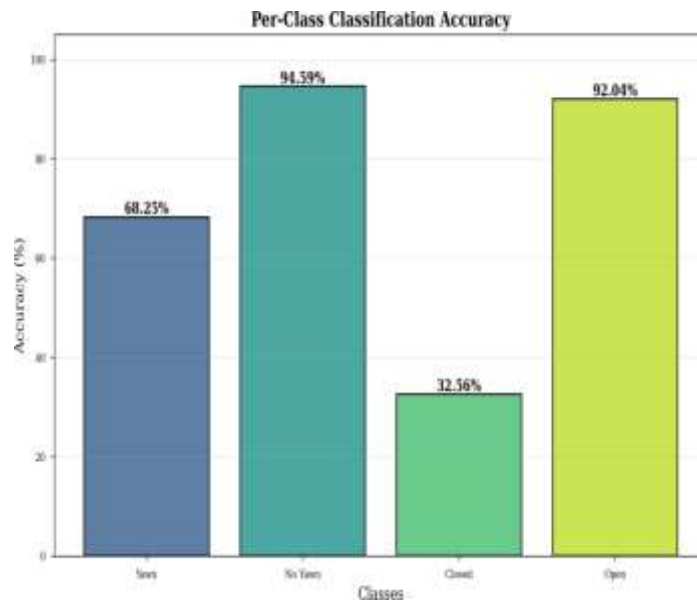


Fig. 4. Normalized confusion matrix for the drowsiness model.

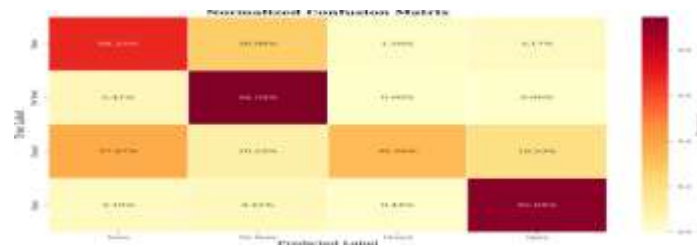


Fig. 5. Combined performance metrics (Precision, Recall, F1-Score) for the drowsiness model.

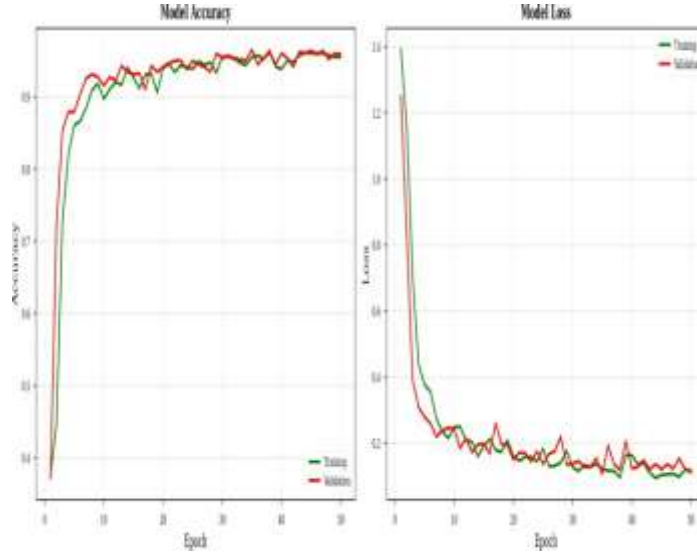


Fig. 6. Detailed per-class accuracy for the drowsiness model.

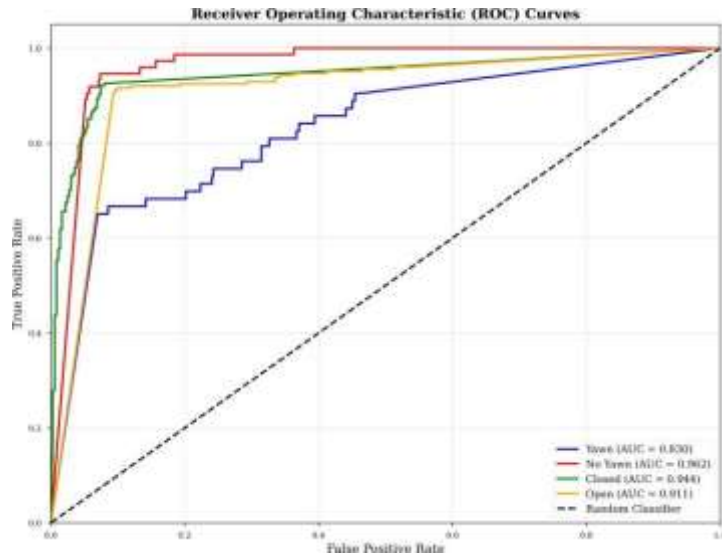


Fig. 7. Receiver Operating Characteristic (ROC) curve for the drowsiness detection model (AUC $\approx$ 0.99).

4.2 Stress Model Validation

Training & Performance: Results from the stress model, trained using the WESAD dataset, are similarly impressive. Accuracy and loss curves successfully converged dur-

ing training (Fig. 8). The model demonstrates high F1-scores for the ‘Stress’ and ‘Baseline’ classes. A high AUC score is confirmed by the ROC curve analysis (Fig. 9), comparable to other models created using the WESAD dataset [8]–[12].

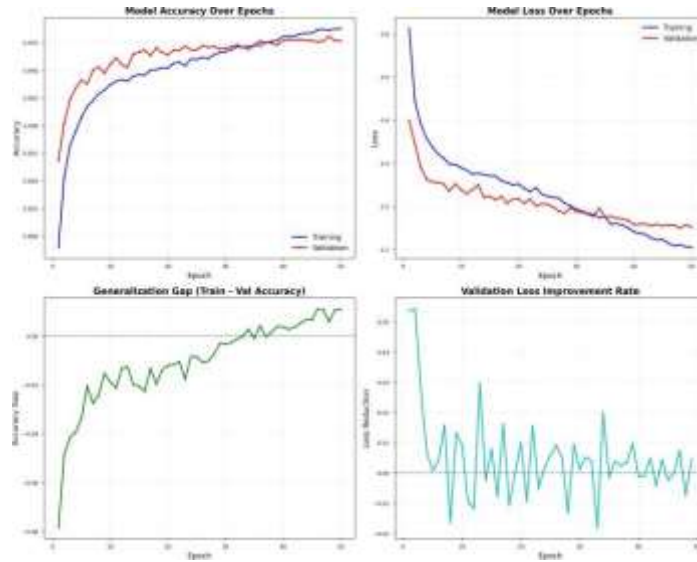


Fig. 8. Training and validation history (accuracy and loss) for the stress detection model.

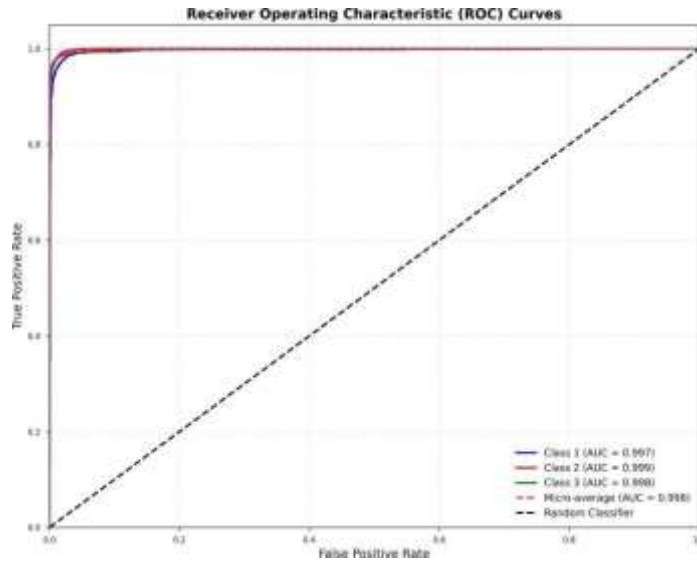


Fig. 9. ROC curves for the stress detection model, demonstrating high AUC scores.

4.3 Validation Summary

Both perception models have been thoroughly validated, confirming that they offer an extremely accurate and trustworthy empirical basis for the intervention system. The high-fidelity inputs ensure that the FusionEngine is operating on meaningful data, allowing the DecisionEngine to make informed and appropriate interventions.

5 Discussion

The primary contribution of this work is the design and implementation of an integrated system that closes the loop between psychophysiological sensing and context-aware intervention. Our experimental results demonstrate that the underlying perception models for drowsiness and stress are highly accurate, providing a solid foundation for the system’s decision-making logic.

To illustrate the system’s end-to-end operation, consider the following **Qualitative Use Case**:

- **10:00 AM:** A user begins working on a task defined in the TaskManager as having high cognitive load and low interrupt tolerance (e.g., “Draft project proposal”). The FusionEngine reports a ‘Normal’ fatigue state.
- **10:45 AM:** After a prolonged period of focus, the stress model begins detecting elevated physiological arousal, and the drowsiness model detects increased blink duration. The FusionEngine’s smoothed fatigue_score rises, and the state transitions to ‘Moderate’.
- **10:50 AM:** The user continues working. The state_duration for the ‘Moderate’ state now exceeds the 300-second threshold defined in decision_engine.py.
- **10:51 AM:** The DecisionEngine’s _handle_moderate rule is triggered. It generates a SchedulerAction of type break, suggesting a 10-minute break with the reason: “Moderate fatigue for 5 minutes.” The intervention is delivered to the user.

This use case highlights the system’s novelty. While many systems have focused on detection [1], [2] or context-awareness in isolation [20], our work presents a novel, integrated system. It moves beyond simply alerting the user to a “high stress” event, synthesizes multiple signals into a stable state, considers temporal dynamics, and cross-references with the user’s current task context before acting [21].

6 Conclusion & Future Work

This paper presents the complete design, implementation, and validation of a context-aware intervention system for managing cognitive fatigue. By successfully integrating high-accuracy, multimodal perception models for drowsiness and stress with a robust fusion engine and a context-sensitive decision engine, we have created a closed-loop system that bridges the critical gap between passive monitoring and active, intelligent support.

While the current system demonstrates a powerful reactive framework, several avenues for future work are evident:

Proactive Task Scheduling: A future version can proactively recommend which task to work on next by using the predicted `fatigue_state` in conjunction with the `cognitive_load` attribute of pending tasks (e.g., suggesting a low cognitive load task when mild fatigue is detected), transforming the system into a proactive recommendation engine [22].

Reinforcement Learning for Personalization: A Reinforcement Learning (RL) agent could use the `get_action_acceptance_rate()` method as a reward signal to gradually learn a personalized intervention policy, modifying break times, suggestion timings, and intervention types to optimize user acceptance and efficacy [21].

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S.A.A.R. : A conversational AI Platform

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Abstract. This paper presents the development of S.A.A.R., an advanced conversational AI platform designed to interpret, process, and respond to user inputs through both speech and text. The system integrates multiple artificial intelligence components such as speech recognition, natural language processing (NLP), decision mapping, and task automation within a unified and modular architecture. S.A.A.R. leverages asynchronous multithreading to enable real-time interaction while maintaining smooth system performance. The platform employs machine learning-driven language understanding to analyze user intent and perform context-specific operations such as system control, information retrieval, and web-based query responses. Experimental results demonstrate that the proposed architecture provides a scalable, efficient, and extensible framework for building intelligent personal assistants using open-source technologies.

Keywords: Artificial Intelligence, Conversational Agent, Speech Recognition, Natural Language Processing, Automation, Real-time Search, Machine Learning, Decision Mapping Model.

1 Introduction

Artificial Intelligence (AI) has revolutionized the way machines interpret, reason, and interact with humans by enabling systems to understand natural language and respond intelligently. Over the past decade, the emergence of voice-driven assistants such as Amazon Alexa, Apple's Siri, and Google Assistant has demonstrated the potential of AI-powered conversational systems to handle real-world tasks autonomously. These intelligent agents combine speech recognition, natural language processing (NLP), and automation techniques to deliver human-like interactions across various domains.

In this context, the proposed system—S.A.A.R. (Just A Rather Very Intelligent System)—has been developed as a modular and extensible conversational AI platform capable of processing both speech and text-based commands. The system integrates multiple functional components including speech recognition, decision mapping, text generation, and task automation within a unified framework. By employing asynchronous multithreading and intelligent query processing, S.A.A.R. ensures real-time responsiveness while maintaining operational efficiency.

The primary objective of S.A.A.R. is to facilitate natural and intuitive communication between users and computers. It enables users to execute system-level operations such as opening applications, retrieving files, performing web searches, or obtaining contextual information through simple spoken or written commands. Unlike traditional command-line interfaces, S.A.A.R. provides a more interactive and adaptive user experience, bridging the gap between human communication and computational intelligence.

2 Literature Review

[1] proposed a Virtual Bot: A Personal Desktop Assistant that utilizes rule-based decision-making to execute local system tasks such as opening applications, searching files, and retrieving online information. Their design emphasized user convenience through command-based task automation and integration with desktop environments. While effective, the system primarily relied on predefined commands, which limited its ability to handle context-aware or dynamic queries. This gap highlights the need for a more adaptive and learning-based conversational model, which the JARVIS framework aims to address through decision mapping and intelligent intent recognition.[2] explored the technical aspects of Voice Assistant Technology in the context of the JARVIS AI model. Their study examined the architecture of AI-driven voice assistants focusing on speech processing, NLP, and machine learning integration. The research discussed various challenges, including speech ambiguity, latency reduction, and intent classification accuracy. The paper underscored the importance of modular design and real-time processing, which directly aligns with the architectural goals of the JARVIS platform developed in this study — particularly in its use of asynchronous multithreading and real-time response generation,[3] introduced ARIVA, an AI-enabled voice assistant that leverages advanced NLP and deep learning algorithms to improve human-computer interaction. Their approach demonstrated significant progress in contextual understanding, enabling the assistant to interpret natural language more effectively and respond with higher precision. ARIVA's use of neural network-based NLP pipelines serves as a foundation for modern conversational systems. However, their implementation required substantial computational resources. In contrast, JARVIS incorporates a lighter-weight yet modular structure, achieving a balance between efficiency and performance by combining rule-based logic with machine learning-driven components.[4] presented JARVIS – An AI Voice Assistant, focusing on enhancing speech interaction using real-time voice processing and multi-task automation. Their work demonstrated the potential of combining multiple AI techniques—speech synthesis, speech recognition, and NLP—to create responsive personal assistants. Although their implementation was limited to specific domains, it laid the groundwork for scalable and multi-domain conversational systems. Building upon their findings, the JARVIS platform proposed in this paper extends such capabilities by integrating an adaptive decision-mapping module and a real-time search engine to handle both offline system commands and dynamic online queries.

3 Proposed methodology

The proposed system, S.A.A.R. (Just A Rather Very Intelligent System), follows a modular and layered architecture that integrates multiple artificial intelligence components into a cohesive conversational framework. The design emphasizes scalability, parallel processing, and real-time responsiveness, enabling efficient execution of both offline system commands and online information retrieval tasks.

The architecture consists of several core modules, each responsible for a specific function within the interaction pipeline:

3.1 Input Acquisition Layer:

This layer is responsible for capturing user inputs in either text or speech format. Speech input is processed through the SpeechRecognition module, which employs automatic speech recognition (ASR) algorithms to convert spoken language into textual data. This allows seamless multimodal interaction between the user and the system.

Libraries Used:

- `speech_recognition` – Converts spoken input into text using Google’s Speech API.
- `pyaudio` – Captures audio in real-time through the user’s microphone.
- `tkinter` / `customtkinter` – Provides an interactive GUI for text-based input.

Working: When the user initiates communication, S.A.A.R. listens through the microphone. The speech signal is recorded and converted to text using `speech_recognition`. Alternatively, the user can type a query directly into the GUI interface.

3.2 Preprocessing and Decision Mapping Layer:

The input text is passed to the FirstLayerDMM (Decision Mapping Model) module, which identifies the intent behind the command. It categorizes the user request into one of several functional domains such as general conversation, real-time search, or system automation. This layer applies rule-based logic along with lightweight NLP models to enhance intent classification accuracy.

Libraries Used:

- `nlk` (Natural Language Toolkit) – For tokenization, stemming, and intent extraction.
- `transformers` (Hugging Face) – For contextual language understanding using pre-trained models like BERT or GPT-based embeddings.
- `spacy` – For entity recognition and syntactic parsing.

Working:

The input text undergoes preprocessing (removal of stop words, punctuation, and normalization). The NLU model then identifies the intent (e.g., “open Chrome,” “play music,” “search the web,” etc.) and relevant entities (application name, website name, etc.).

3.3 Processing and Response Generation Layer:

Depending on the identified intent, the system routes the command to the appropriate backend service. For general or conversational queries, the ChatBot module utilizes NLP-based text generation to produce human-like responses. For web-based or current information requests, the RealtimeSearchEngine module performs live searches and retrieves relevant data from online sources. The Automation module handles direct system-level

operations such as opening applications, managing files, or executing system commands.

Libraries Used:

- `os` and `subprocess` – To execute system-level commands (e.g., open applications, folders, etc.).
- `pywhatkit` – For web automation tasks (e.g., sending messages, playing YouTube videos).
- `wikipedia` – For fetching summarized information from Wikipedia.
- `requests` and `BeautifulSoup` – For web scraping and data retrieval.
- `pyautogui` – For mouse and keyboard automation.

Working:

Based on the mapped task, S.A.A.R. executes commands such as launching applications, fetching information, or performing automated actions. For instance, “Open YouTube” launches the browser and navigates to YouTube, while “Tell me about AI” retrieves a Wikipedia summary.

3.4 Speech and Output Generation Layer:

Once the response or action output is generated, the `TextToSpeech` module converts textual responses into natural-sounding speech using neural synthesis algorithms. Simultaneously, the `GraphicalUserInterface` (GUI) displays the output text and system status to the user, ensuring synchronized visual and auditory feedback.

Libraries Used:

- `gtts` (Google Text-to-Speech) or `pyttsx3` – For converting textual output into speech.
- `tkinter` GUI – For displaying textual output.

Working:

The generated response, whether it’s the result of a search or system command confirmation, is both displayed on the GUI and spoken aloud using a text-to-speech engine. This ensures natural, two-way human-computer interaction.

3.5 Thread Management and Real-Time Execution:

To maintain responsiveness, S.A.A.R. employs multithreading and asynchronous execution using Python’s `threading` and `asyncio` libraries. Independent threads handle voice input, decision processing, and GUI updates concurrently, allowing uninterrupted communication and efficient resource utilization.

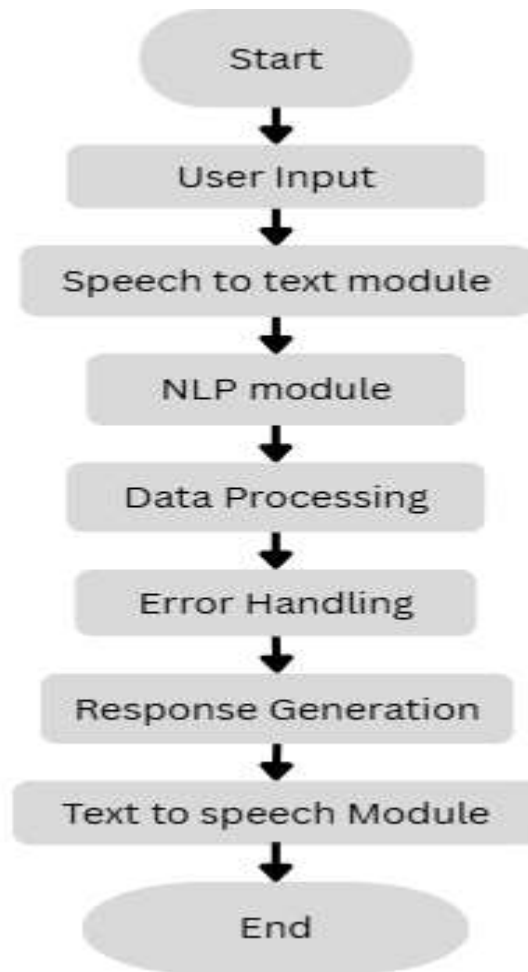
Libraries Used:

- `threading` – For parallel execution of voice listening, task processing, and output generation.
- `asyncio` – For asynchronous handling of input/output operations.

Working:

Each major task — listening, processing, and responding — runs in a separate thread, ensuring real-time system performance without input lag or freezing.

The system’s workflow begins with user input (speech or text), followed by intent detection, decision mapping, and module activation based on the identified task type. The results are then presented through text and voice outputs, ensuring a smooth, interactive user experience.



This modular approach not only enhances fault tolerance and reusability but also allows easy integration of advanced AI models in the future. By combining automation, real-time data retrieval, and NLP-based understanding, S.A.A.R. demonstrates an effective methodology for building intelligent, responsive, and adaptable conversational assistants.

4 Results and discussion

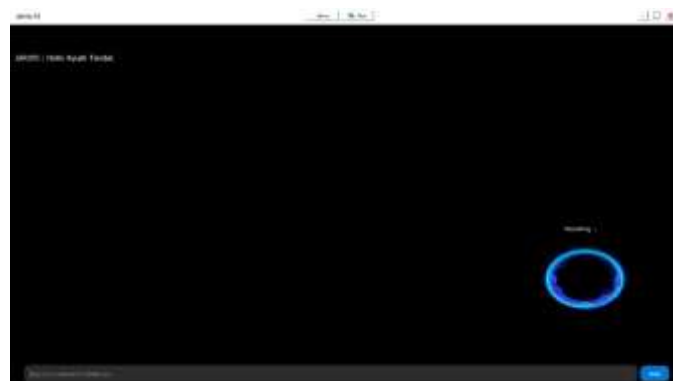


Figure 1. User friendly interface



Figure2. S.a.a.r. listening speech input

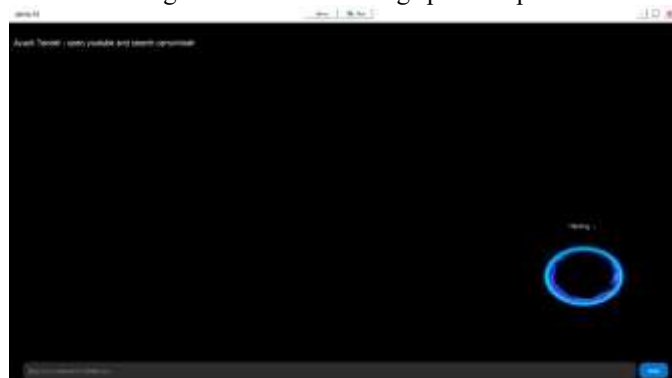


Figure 3.Processing the given input



Figure 4.Task automation

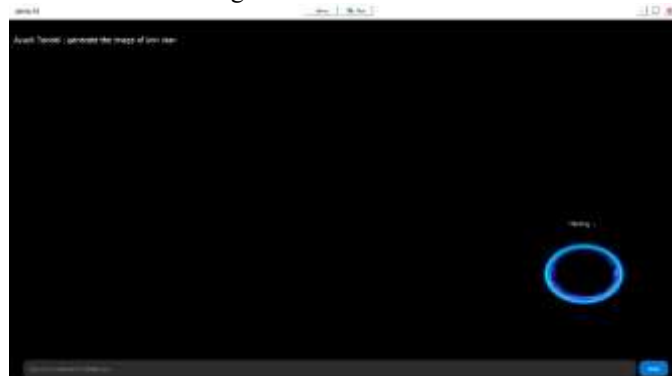


Figure5. taking user input

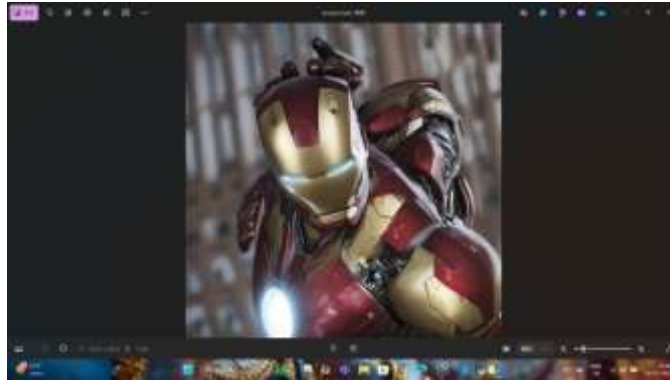


Figure 6. Image Generation

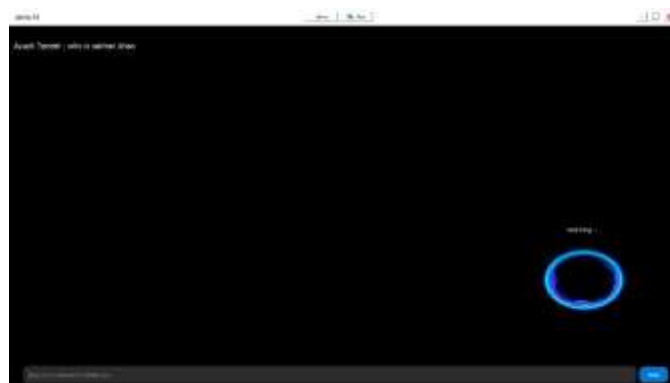


Figure 7. Taking user input



Figure 8. Giving text output

5 Conclusion & Future Work

The S.A.A.R. AI Conversational Platform demonstrates the effectiveness of integrating diverse artificial intelligence components into a cohesive, intelligent framework capable of performing speech understanding, natural language processing, decision-making, and automation. The system's modular architecture, supported by asynchronous processing, ensures efficient task execution and real-time responsiveness. By utilizing Python-based open-source libraries for speech recognition, text-to-speech conversion, automation, and NLP-driven intent mapping, S.A.A.R. achieves a balance between simplicity and performance. The project validates that it is possible to build an intelligent personal assistant with advanced functionality without relying on heavy commercial frameworks, making it both scalable and adaptable to various computational environments.

The current implementation of S.A.A.R. highlights its potential as a foundational model for future conversational AI systems. Moving forward, the platform can be enhanced by incorporating advanced contextual understanding and emotional intelligence to deliver more natural and continuous interactions. The integration of large language models can further improve its reasoning ability, conversational accuracy, and adaptability to user preferences. Expanding its language processing capabilities to support multiple languages and regional dialects would allow it to cater to a wider audience. Moreover, deploying the system on cloud infrastructure would enhance scalability and facilitate access across multiple devices, while the inclusion of Internet of Things (IoT) connectivity would extend its usability into smart environments. Emphasis on improving data security and privacy mechanisms will also be critical to ensure safe and ethical use of AI-powered interactions.

In conclusion, S.A.A.R. stands as a comprehensive framework that bridges human communication and intelligent automation, representing a significant step toward developing efficient, context-aware, and adaptive AI assistants. Its modularity and extensibility make it a promising foundation for future innovations in both personal and industrial conversational systems.

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Simplifying Health Insurance Through AI: Policy Analysis and Guidance

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Abstract. Making informed financial decisions is important, especially in health insurance, where both money and personal well-being are involved. Many policyholders find insurance documents difficult to understand due to complex terms such as co-payments, room rent limits, sub-limits, and waiting periods, which can lead to partially approved claims and unexpected financial stress. In this paper, we present an AI-based health insurance assistance platform aimed at improving transparency and helping users make better policy decisions. Existing platforms often provide limited clarity or fragmented information [8], so our system organizes this information into a single, structured interface. The platform includes a personalized dashboard, simplified explanations of policy clauses, claim guidance steps, a branch locator, and a feedback mechanism that can help regulatory bodies like IRDAI monitor insurance providers. For policy selection, an AI-driven recommendation module analyzes user inputs and matches them with suitable policies using MongoDB-based filtering and natural language processing. The system also enables side-by-side comparison of selected policies by evaluating coverage amount, premium, and waiting period through database queries, and provides a summarized explanation of which option may better suit the user's needs. An integrated AI assistant, built using Semantic Kernel and connected to structured MongoDB data, answers user queries by retrieving verified policy information. The platform is developed using React for the frontend and MongoDB and Supabase for backend and data management. Overall, the system focuses on clarity, structured comparison, and guided assistance, demonstrating how AI can support more transparent and informed decision-making in health insurance [7], [15].

Keywords: Health Insurance, Artificial Intelligence, Policy Analysis, Transparency, AI Agent, FinTech

1 Introduction

Making informed financial decisions has become increasingly important, especially in the area of health insurance where both financial stability and personal well-being are involved. Although the insurance sector has undergone significant digital transformation, health insurance policies are still difficult for many users to understand. Policy documents often include technical terms such as co-payments,

room rent limits, sub-limits, exclusions, and waiting periods, which are not always clearly interpreted by policyholders [7]. As a result, many individuals face reduced claim settlements or unexpected expenses during medical emergencies.

In recent years, several digital platforms have been introduced to simplify policy comparison and advisory services. However, we observed that many of these platforms either provide limited transparency or present information in a scattered manner [8]. Users frequently rely on agents or basic comparison tools that do not fully consider personal requirements such as budget constraints, age-specific coverage needs, or location-based policy conditions. This creates a gap between policy availability and actual policy understanding.

To reduce this gap, we propose an AI-driven health insurance assistance platform focused on clarity, personalization, and structured decision support. The system provides a centralized dashboard where users can view policy details, understand company performance indicators, access guided claim procedures, and locate nearby branch offices.

For personalized recommendations, we designed a module that validates user inputs such as age, budget, and coverage preferences directly against structured policy data stored in MongoDB. Instead of relying on general summaries, the system performs attribute-based filtering and applies NLP-based semantic matching to compare user requirements with actual policy clauses. This ensures that recommendations are generated from verified data.

The platform also includes a structured policy comparison module that allows users to evaluate selected policies across parameters such as premium amount, coverage limit, waiting period, and location applicability [11]. By performing direct database-level comparisons, the system maintains consistency and reduces ambiguity in evaluation.

To further improve usability, we integrated an AI assistant built using Semantic Kernel architecture. The assistant supports multilingual queries and retrieves responses directly from structured data, enabling real-time clarification of policy-related questions.

The system is implemented using React for the frontend, MongoDB for structured data storage, Supabase for backend services, and an integrated AI agent for intelligent processing. Overall, the proposed approach aims to improve transparency, strengthen user confidence, and simplify the health insurance decision-making process [7], [15].

1.1 Research Gap

What Exists. Existing digital solutions for agents and brokers fall into four broad

categories:

- Single-insurer portals, supporting quoting, issuance, and claims servicing for tied agents [17].
- PoSP/B2B distribution platforms, enabling multi-insurer sales, commissions, and customer lifecycle tracking [18], [19].
- Generic CRMs and dashboards, focused on lead management, renewals, and basic task automation [21].
- Consumer-facing aggregators, some of which offer agent referral models but prioritize self-service tools for buyers [23], [24].

These tools enable access to data across multiple sources—insurer APIs, policy documentation, and client records—but agents must manually synthesize information to make informed recommendations.

Why This Is Insufficient. Despite digital progress, current systems fall short in several critical ways:

- Orientation mismatch: Most platforms are designed to maximize transaction speed and volume, offering little support for structured suitability reasoning or clause-level transparency [18], [19].
- Fragmentation: Agents are required to navigate between insurer portals, PoSP apps, and CRMs without a unified advisory dashboard [20], [21].
- Regulatory disconnect: Digital platforms do not integrate IRDAI complaint histories, regulatory enforcement data, or suitability controls into the advisor workflow, despite mounting emphasis on these areas [22].
- Persistent advisory risks: IRDAI's data shows continued mis-selling trends, suggesting that current platforms do not adequately bridge the information and suitability gap [22].

What Can Be Done Differently. To address these limitations, Ask My Policy introduces a complementary AI-enabled architecture that introduces three key innovations:

1. Structured policy knowledge base: A MongoDB-backed repository of cross-insurer policy clauses (e.g., co-pays, sub-limits, exclusions) structured for semantic querying and comparison.
2. AI-based advisory assistant: An agent-facing interface powered by Semantic Kernel, capable of clause-aware Q&A and suitability scoring, grounded in verified policy and regulatory data.
3. Embedded regulatory signals: Integration of IRDAI complaint statistics, policy enforcement outcomes, and audit history into the advisor dashboard to enable transparent, traceable guidance.

This system complements existing PoSP and CRM tools by prioritizing decision quality and explainability over sales volume. It aims to enhance agent trustworthiness and mitigate regulatory risk at the point of advice.

2 Literature Review

2.1 Digitalization of Insurance Intermediation

Recent studies discuss how digitalization is reshaping broker and agency operations within the insurance sector. Researchers highlight improvements in workflow automation, cost efficiency, analytics integration, and customer interaction through AI-supported systems [25]. However, several authors caution that without careful implementation, excessive automation may reduce the advisory value traditionally offered by brokers.

Industry reports also emphasize the growing importance of digital enablement tools. Modern platforms integrate CRM systems, automate documentation processes, and assist agents in customer engagement activities [26]. Commonly cited tools include quotation software, lead management systems, marketing automation solutions, and digital document collection frameworks [27].

Although these developments enhance operational productivity, most platforms primarily focus on sales efficiency. Advanced analytical capabilities such as clause-level interpretation, structured suitability evaluation, or regulatory risk integration are rarely addressed in depth [20], [25]–[27].

2.2 Agent-Centric PoSP and B2B Distribution Platforms

India's insurtech growth has contributed to the emergence of digital Point-of-Sale Person (PoSP) ecosystems [19]. These platforms aim to expand distribution reach by equipping agents with mobile-first applications and centralized access to insurer products.

For example, Turtlemint aggregates policies from multiple insurers while supporting digital issuance and training modules through its academy platform. RenewBuy operates a large advisor network and provides multi-product comparison and issuance workflows. Other SaaS-based solutions such as Heph, VISoF, and Mzapp offer white-labeled platforms with integrated insurer APIs and onboarding pipelines [18], [19].

While these systems improve accessibility and scale distribution networks, their primary design objective remains sales facilitation. Neutral comparison mechanisms, structured explanation of policy clauses, and embedded suitability analytics remain limited or absent [18]–[20].

2.3 Insurer-Owned Agent Portals

In addition to independent PoSP platforms, several insurers maintain proprietary digital portals for their tied agents. These portals generally include features such as proposal submission, issuance tracking, and policy servicing workflows. For instance, Niva Bupa provides digital policy management interfaces, while SBI General Insurance supports structured issuance and claims tracking mechanisms [28], [29].

However, these platforms operate within closed ecosystems. Agents are restricted to a single insurer's product portfolio, which limits cross-company comparison and reduces the possibility of neutral advisory recommendations [28], [29].

2.4 Generic CRM and Agency Management Tools

Independent agents frequently rely on generic CRM systems to manage leads, renewals, and customer communications. Certain dashboards consolidate agent credentials, commission tracking, and contract documentation into unified interfaces [21]. Broader CRM platforms further assist with campaign management, automated messaging, and digital document sharing [20], [27].

Despite supporting administrative efficiency, such tools lack domain-specific analytical capabilities. They do not provide structured insurance clause interpretation or suitability assessment mechanisms tailored to advisory decision-making.

2.5 Regulatory Concerns and Mis-Selling

Even with increasing digital adoption, concerns regarding policy mis-selling continue to surface. Reports indicate a rise in complaints categorized under unfair business practices, emphasizing the need for stronger suitability frameworks and accountability mechanisms [22]. Regulatory bodies advocate proactive monitoring and improved distribution-level safeguards.

However, most existing digital tools remain reactive rather than preventive. Suitability reasoning and complaint trend visibility are generally not embedded directly within agent workflows, limiting their effectiveness at the point of sale.

3 Objectives

The main objectives of this study are as follows:

1. **Promote Transparency:** Bridge the gap between customers and insurance companies by providing comprehensive company analysis and integrating verified data from IRDAI. This aligns with the growing need for explainable AI (XAI) to build user trust [13]. This ensures that users can make informed decisions based on facts rather than relying solely on recommendations from friends or family, a critical factor in user adoption of AI advisors [14].
2. **Policy Comparison:** MongoDB is used to store and manage policy data, while MCP Server handles backend processing to enable quick and accurate policy comparison.
3. **AI-Driven Policy Recommendations with NLP-Based Coverage Matching:** Generate personalized policy recommendations derived directly from user-provided inputs, which are stored in MongoDB and filtered to match relevant policy attributes. Coverage requirements specified by the user are evaluated using NLP-based semantic similarity to determine whether each policy sufficiently satisfies the requested features, ensuring accurate and

context-aware policy matching.

4 Methodology

4.1 AI-Assisted Policy Comparison Using MongoDB

Policy comparison is now performed based on the specific policies selected by the policyholder. Once the user selects the policies to compare, the system retrieves the corresponding records from MongoDB and evaluates key parameters such as premiums, coverages, waiting periods, and exclusions using direct database queries. The results are presented in a structured, table-based comparison for clarity. Additionally, an AI layer analyzes the extracted parameters and provides a recommendation indicating which policy best aligns with the user's stated requirements.

4.2 AI Agent Workflow Using Semantic Kernel

The AI agent is implemented using Semantic Kernel, integrated with a MongoDB plugin for intelligent parameter verification. When a user submits a query, the Semantic Kernel orchestrator interprets the input and uses the MongoDB plugin to validate policy attributes against the user's stated requirements. Instead of relying on vector databases, the AI agent directly queries MongoDB to verify coverage details, eligibility conditions, and related policy parameters. The LLM then generates an informed, context-grounded response based on the verified data, ensuring accuracy, consistency, and transparency in policy explanations.

Phase 1: System Initialization.

- Load Environment: Retrieve API keys (GROQ_API_KEY) and database credentials (MONGODB_CONNECTION).
- Connect Database: Initialize MongoDBService to connect to the AskMyPolicy database and the compare collection.
- Initialize Agent:
 - Instantiate the custom GroqChatCompletion client.
 - Initialize the Semantic Kernel.
 - Register Tools: Wrap the MongoDB service methods into a PolicyPlugin and register it with the Kernel. This gives the AI "skills" to fetch data (e.g., get policy coverage, get premium details).

Phase 2: The Interaction Loop.

- Start Interface: Enter a while True loop to accept user input via the console.
- Receive Input: Capture the user's query (e.g., "Does Policy X cover cancer?").
- Trigger Agent: Pass the input to the agent.ask() method.

Phase 3: Processing & Tool Execution.

- Construct Context:
 - Create a ChatHistory.
 - Inject the System Prompt (Rules: "You are an insurance assistant... always use plugins...").
 - Append the User Message.
- Configure Execution:
 - Set FunctionChoiceBehavior.Auto(), allowing the LLM to decide if it needs to query the database or answer directly.
- LLM Inference (Round 1):
 - Send the chat history to Groq via GroqChatCompletion.
 - The LLM analyzes the prompt. If it detects a need for data (e.g., premium information), it requests a specific function call from PolicyPlugin.
- Data Retrieval (Automated):
 - The Kernel identifies the requested function (e.g., search policies by coverage).
 - It executes the corresponding Python method in MongoDBService.
 - The MongoDB query runs, and JSON results are returned to the LLM.
- LLM Inference (Round 2):
 - The LLM receives the raw JSON data from the database.
 - It synthesizes a natural language response based on the data and the System Prompt constraints (e.g., "Answer in 10–15 lines").

Phase 4: Output.

- Return Response: The generated text is returned to the main loop.
- Display: Print the Assistant response to the console.
- Repeat: Wait for the next user input.

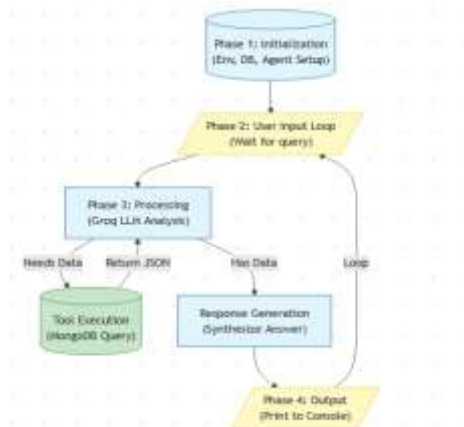


Fig. 1. High-Level Algorithm Diagram of the Semantic Kernel Workflow.

4.3 AI-Driven Policy Recommendations with NLP-Based Coverage Matching

The recommendation module generated personalized outputs based solely on user-provided input parameters. These inputs were stored in MongoDB and filtered using domain-specific query conditions. Coverage requirements were evaluated using NLP-based semantic similarity to determine whether each policy aligned with the user's stated needs. The system then produced data-backed recommendations that clearly indicated how well each policy satisfied the requested coverage criteria.

5 System Design

The proposed system follows a modular multi-tier architecture. We separated the application into distinct layers so that the user interface, business logic, and AI components operate independently. This structure makes the system easier to maintain and allows future expansion without major redesign.

The frontend is developed using React.js and handles user interaction, dashboards, and policy comparison views. Supabase is used for authentication and basic backend services, including secure session handling and user data management.

The core intelligence layer is built using Semantic Kernel integrated with a custom MongoDB plugin. This AI component acts as a coordinating layer between user inputs and structured policy data. When a user enters parameters such as age, coverage preference, or budget, the system directly queries MongoDB collections to validate and retrieve matching policy attributes.

The system performs structured database-level evaluation. This approach enables faster response generation and ensures that outputs are based strictly on verified policy records.

The AI layer then formats the validated results into natural language explanations to improve user understanding.

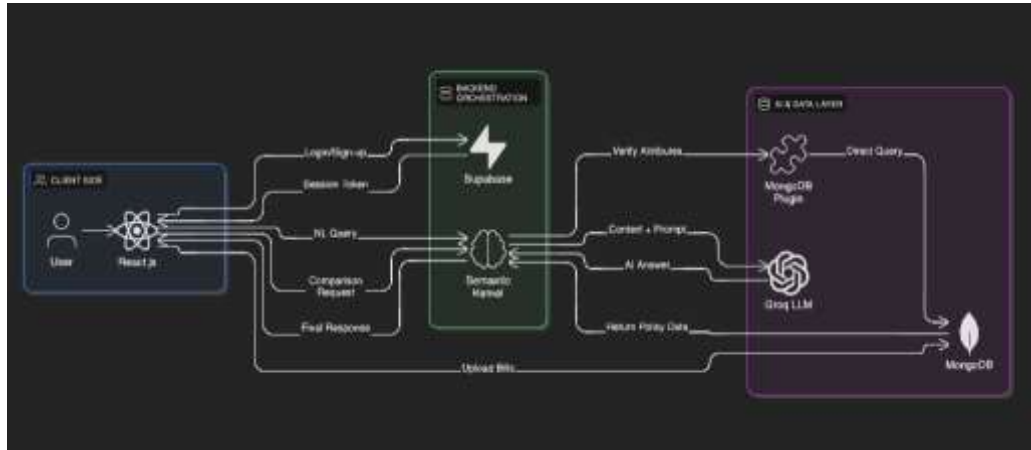


Fig. 2. System Architecture.

6 Results

The developed system demonstrates key functionalities across its modules, ensuring effective insurance advisory support.

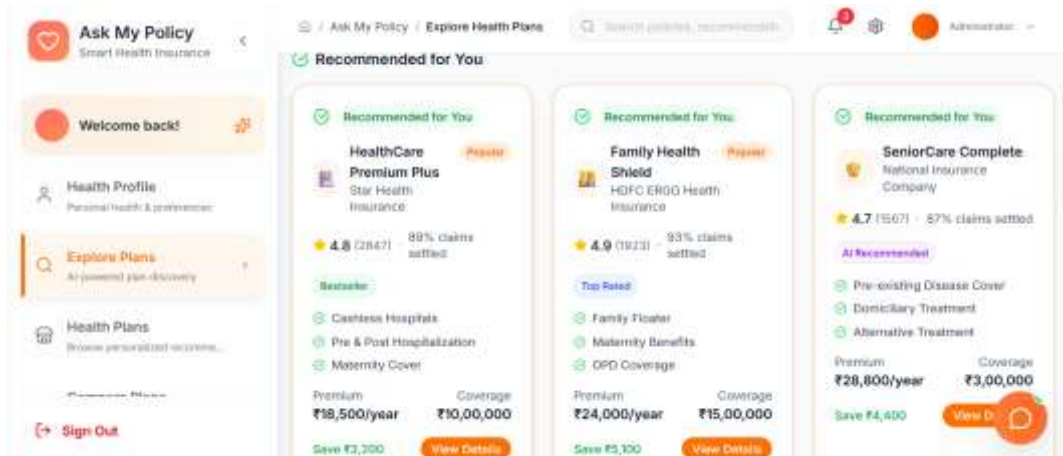


Fig. 3. Policy recommendation with AI.

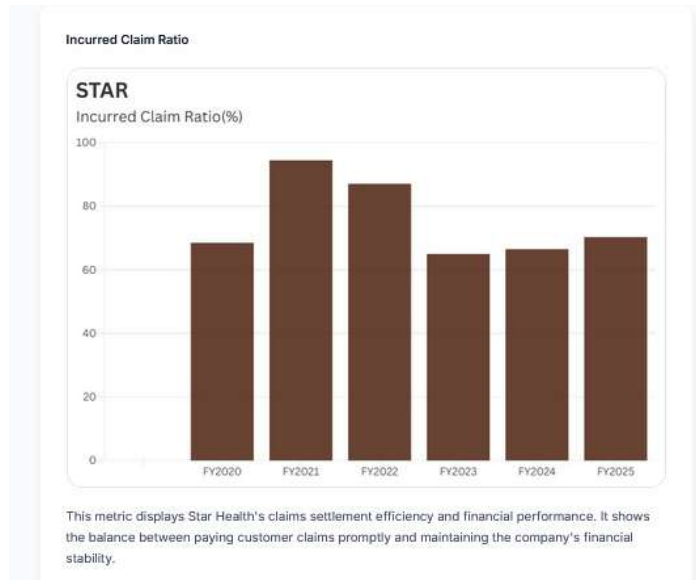


Fig. 4. Company analysis.

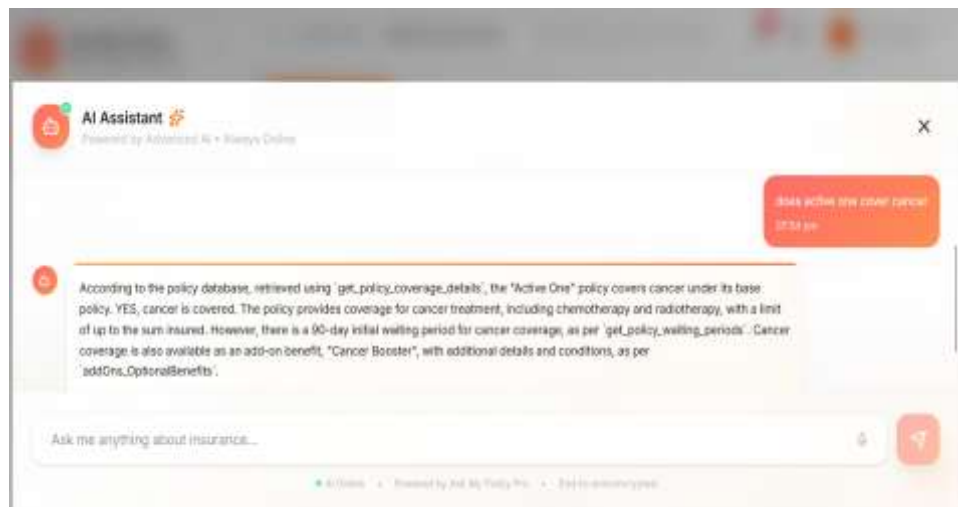


Fig. 5. Chatbot response.

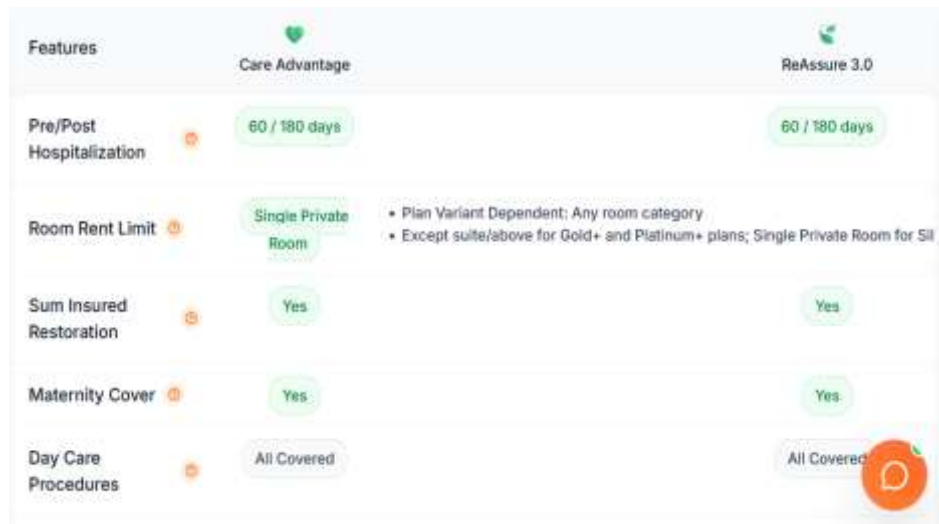
7 Experimental Setup

At the current stage of development, the system database contains more than 35 insurance policy documents. These documents were collected directly from the official policy wordings published on the respective company websites to ensure authenticity

and reliability of the source material.

The dataset includes policies from seven major insurance providers: HDFC Life, ICICI Prudential Life Insurance, Niva Bupa, Care Health Insurance, Bajaj Allianz, Star Health and Allied Insurance, and Aditya Birla Health Insurance. The policy documents were systematically analyzed, and relevant information was extracted and transformed into a structured format to enable efficient querying and retrieval. This structured data was subsequently stored in a MongoDB database, which functions as the primary data repository of the system.

The system architecture integrates Semantic Kernel as the AI orchestration framework. A MongoDB plugin was implemented within this framework to support structured function calling. When a user submits a query, the AI agent invokes the appropriate predefined function through the plugin interface, which then retrieves the relevant structured information from the MongoDB database. The retrieved data is passed back to the agent for response generation. This architecture ensures controlled database access, accurate information retrieval, and modular interaction between the language model and the data layer, thereby minimizing the risk of generating unsupported or hallucinated responses.



Features	Care Advantage	ReAssure 3.0
Pre/Post Hospitalization	60 / 180 days	60 / 180 days
Room Rent Limit	Single Private Room	• Plan Variant Dependent; Any room category • Except suite/above for Gold+ and Platinum+ plans; Single Private Room for Sil
Sum Insured Restoration	Yes	Yes
Maternity Cover	Yes	Yes
Day Care Procedures	All Covered	All Covered

Fig. 6. Policy comparison with the help of semantic kernel.

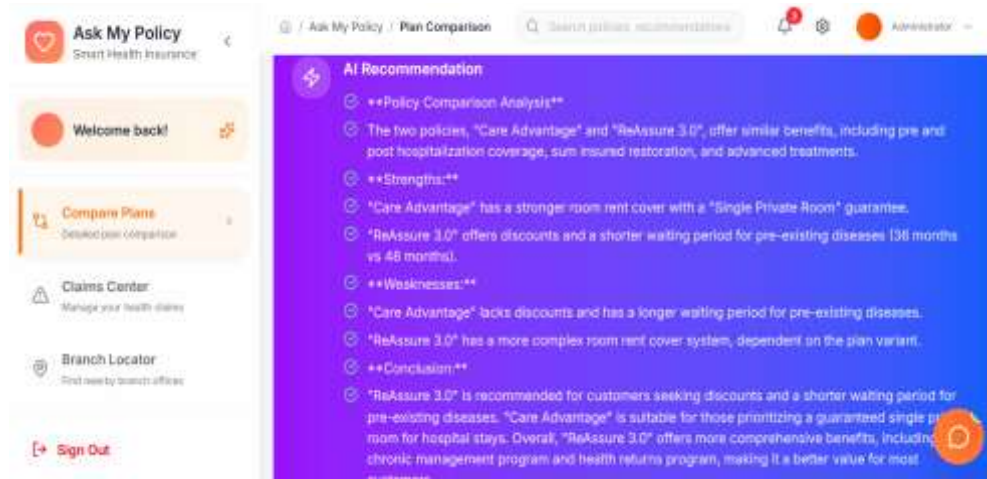


Fig. 7. AI review of the comparison.

The language model employed in this study is LLaMA 3.3 70B Versatile, a transformer-based model optimized for instruction following, structured function calling, and tool usage. The model supports long-context conversational tasks and demonstrates strong capability in handling schema-aware and domain-specific queries. It was selected primarily due to its structured function-calling abilities, accurate schema understanding, and suitability for handling precise, policy-related queries. The model was configured with the following parameters: model id set to "llama-3.3-70b-versatile," temperature set to 0.3, max tokens set to 800, and function choice behavior set to Auto(). The relatively low temperature value was chosen to promote deterministic and consistent outputs, which is essential in insurance-related information systems where accuracy is critical.

For inference, the system utilizes the Groq API infrastructure, which operates on Low Processing Unit (LPU) hardware optimized for high-throughput and low-latency large language model inference. This infrastructure enables efficient real-time processing of user queries. Semantic Kernel manages tool orchestration, function invocation, prompt execution control, and overall model configuration, ensuring that responses are generated through structured tool calls rather than unrestricted text generation.

User testing was conducted through the system's graphical user interface. Participants evaluated usability, clarity, and overall interaction experience. The feedback indicated that users perceived the interface as simple, visually appealing, intuitive, and easy to understand. These findings suggest that the system design effectively supports user-friendly interaction while maintaining technical robustness in structured data retrieval and language model integration.

7.1 System Outcomes

The developed system achieved the following outcomes:

- **User Authentication and Security:** A secure login and signup system validates user identity and ensures authorized access.
- **AI-Driven Q&A via Semantic Kernel and MongoDB Plugin:** The system delivered accurate, parameter-specific answers by leveraging Semantic Kernel integrated with the MongoDB plugin. User queries were validated directly against stored policy parameters, enabling precise, context-aware responses without requiring external vector stores.
- **Policy Comparison Through Direct MongoDB Query Evaluation:** Policy comparison results showed that users could select any set of policies, after which the system fetched and compared attributes such as premiums, coverage limits, waiting periods, and exclusions purely through structured MongoDB queries. The comparisons were presented in a clear tabular format, enabling straightforward evaluation of differences.
- **AI-Driven Policy Recommendations Based on User Inputs:** The recommendation results demonstrated effective personalization, as the AI evaluated user-provided requirements and matched them to policy clauses using NLP-based semantic similarity. The system identified whether the requested coverage was present and recommended the most suitable policy based on coverage alignment, premium, and relevant conditions.

FUNCTION	CORRECT ANSWERS	TOTAL QUERIES	ACCURACY
GET_POLICY_BY_NAME	40	40	100
SET_POLICY_COVERAGE_DETAILS	40	40	100
POLICY_PREMIUM_DETAILS	35	40	87.5
WAITING_PERIOD	30	40	75
POLICY_EXCLUSIONS	40	40	100
POLICY_SPECIFIC_COVERAGE	35	40	87.5

Fig. 8. Evaluation Matrix of Semantic Kernel–Based Function Execution.

Figure 8 presents the evaluation matrix of the Semantic Kernel–based function execution framework. The evaluation was conducted by testing each predefined system

function with 40 structured queries. The table reports the number of correct answers, total queries, and the corresponding accuracy percentage.

The results show 100% accuracy for functions such as `GET_POLICY_BY_NAME`, `GET_POLICY_COVERAGE_DETAILS`, and `POLICY_EXCLUSIONS`. These functions directly invoke structured database calls and return deterministic outputs from MongoDB without additional transformation or interpretive processing. Since the Semantic Kernel framework performs controlled function invocation and retrieves exactly the values stored in the database schema, the output precisely matches the underlying MongoDB records. As a result, no deviation or hallucinated content is observed, leading to complete accuracy.

For functions such as `POLICY_PREMIUM_DETAILS`, `WAITING_PERIOD`, and `POLICY_SPECIFIC_COVERAGE`, the observed accuracy is lower (87.5% and 75%). These functions require traversal of nested document structures and multi-level schema fields within MongoDB. The reduction in accuracy is primarily attributable to complexities in nested key extraction, hierarchical field mapping, and minor response structuring variations during function execution. Importantly, these deviations do not represent fabricated or hallucinated outputs; rather, they reflect edge cases in structured data retrieval from deeply nested attributes.

The evaluation demonstrates that when function calls map directly to flat or clearly defined schema fields, the system achieves deterministic and fully accurate responses. For nested or composite data structures, improvements in function routing logic, enhanced schema normalization, stricter field validation, and refined extraction rules are expected to increase precision. With targeted refinements in nested document handling and structured response formatting, these functions are projected to approach the same deterministic accuracy observed in the other evaluated categories.

Overall, the results validate the reliability of the Semantic Kernel orchestration mechanism in enforcing structured tool calls and controlled database access. The architecture effectively minimizes unsupported response generation and ensures high-confidence, schema-aligned outputs suitable for insurance-domain advisory systems.

8 Comparative Analysis of Insurance Platforms

To evaluate the positioning and functionality of the proposed solution, a comparison was conducted across the most common categories of digital insurance platforms currently used by agents, brokers, and consumers. The comparison is based on criteria such as clause-level analytics, AI decision support, and regulatory integration.

Table 1. Comparison of Agent/Broker-Facing Insurance Platforms

Feature	Insurer Portals	PoSP Platforms	CRMs	Ask My Policy
Target User	Tied Agents	Agents/ Brokers	Independent Agents	Advisors/Users
Insurer Scope	Single	Multi	Manual Input	Multi (DB backed)
Clause Analysis	No	Partial	No	Yes
AI Support	None	Limited	Workflow Only	Semantic Kernel
Regulatory Data	Not Integrated	Not Integrated	No	Fully Integrated
Suitability Logic	Manual	Basic Logs	CRM Notes	Auto Rationale
Audit Trail	No	Sales logs	CRM Logs	Scoring + Logs

9 Regulatory Framework, Privacy & Data Security

9.1 Regulatory Classification: Technology Service Provider

"Ask My Policy" operates under a Technology & Marketing Service Provider model, distinct from insurance solicitation or broking.

- **Non-Intermediary Status:** The platform functions solely as an informational interface and lead generation tool. It does not underwrite risk, issue policies, or settle claims.
- **Role Definition:** We act as a bridge, utilizing AI to structure public information and qualify user intent. The actual solicitation and sale of insurance are conducted exclusively by the authorized agents or agencies to whom the leads are transferred.
- **Compliance Boundary:** By strictly limiting our scope to pre-purchase education and consensual lead routing, the platform operates as a digital marketing facilitator for licensed entities, removing the requirement for an IRDAI Direct Broker or Web Aggregator license.

9.2 Data Privacy Strategy (DPDP Act, 2023 Alignment)

Given the sensitive nature of health and financial data, our architecture is designed to be "Privacy-First" to build user trust and ensure compliance with India's Digital Personal Data Protection Act.

- **Explicit Consent Architecture:**
 - **Lead Transfer Consent:** No user data is shared with any agent or agency without a distinct, affirmative action (e.g., "Request Call Back" or "Connect with Expert").
 - **Granular Permissions:** Users retain control over what specific data points (e.g., age, city, pre-existing conditions) are shared with the agent versus what is kept private on the platform.
- **Purpose Limitation:** Data collected by the AI Chatbot and Dashboard is strictly processed for the purpose of generating policy comparisons and managing the user's personal dashboard. It is never sold to third-party data brokers or unauthorized entities.
- **Right to Erasure (The "Forget Me" Protocol):** Users have a one-click option in their dashboard to permanently delete their profile, chat logs, and stored policy documents from our servers, complying with the "Right to Erasure" mandate.

9.3 User Data Security & Infrastructure

To protect the personal documents and chat history stored on the platform, we employ banking-grade s

Appendix A

Survey Findings

A survey was conducted among a group of individuals to identify the gaps and challenges faced in the current health insurance ecosystem. The responses highlighted the following key issues:

- **Communication Gap:** Participants reported a lack of transparency and clarity in interactions with agents and companies, making it difficult to fully understand policy terms.
- **Policy Comparison Challenges:** Although comparison platforms exist, users still find it difficult to effectively compare policies based on their unique needs such as budget, coverage, and age group.
- **Claim Process Issues:** Many respondents expressed dissatisfaction with the claim settlement procedure, describing it as time-consuming and often complicated.
- **Customer Support Concerns:** Feedback indicated that customer support services are not efficient or responsive enough, leaving users frustrated during critical times.

These insights reaffirm the need for a more transparent, user-friendly, and technology-driven platform to bridge the gap between insurance companies and policyholders.

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