A SENSING COMMUNICATION AND COMPUTING APPROACH FOR VULNERABLE ROAD USERS SAFETY

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Abstract
Most fatal road accidents in urban areas involve Vulnerable Road Users (VRUs) such as pedestrians, cyclists, and motorcyclists. This paper proposes a multi-sensing, communication, and computing approach to prevent potential collisions between vehicles and VRUs by predicting hazardous situations in advance and delivering timely notifications to both parties. The system aggregates real-time data from smart-city infrastructure (cameras, radars, LiDARs), On-Board Units (OBUs) in vehicles, and personal devices carried by VRUs (smartphones and smartwatches). Data is fused using advanced collision-detection algorithms and communicated through multiple standards and wireless technologies including ITS-G5, C-V2X, LTE, 5G (and future 6G). Edge computing and multihoming techniques are employed to achieve low-latency predictions. The proposed system was evaluated in a real-world scenario with actual sensors, vehicles, and VRUs. Results demonstrate high prediction accuracy, very low delay, and effective collision avoidance, highlighting the importance of 5G, edge computing, and hybrid communication for reliable VRU safety in smart cities.

Keywords: Vulnerable Road Users (VRU), Sensing-Communication-Computing, Collision Prediction, Sensor Fusion, Edge Computing, 5G, ITS-G5, C-V2X, Smart City Safety.

I.Introduction

Road traffic accidents remain a leading cause of fatalities worldwide, with Vulnerable Road Users (VRUs) — pedestrians, cyclists, and motorcyclists — being disproportionately affected due to their lack of physical protection. Traditional safety systems focus primarily on vehicle-to-vehicle interactions and often fail to provide adequate protection for VRUs in dynamic urban environments.

This paper presents a comprehensive sensing, communication, and computing framework that leverages multi-source data from smart-city infrastructure, connected vehicles, and VRU personal devices. By fusing sensor data and employing real-time collision-prediction algorithms, the system proactively detects potential hazards and issues timely warnings to both drivers and VRUs. The architecture supports multiple wireless technologies (ITS-G5, C-V2X, LTE, 5G) and incorporates edge computing for ultra-low latency. Experimental evaluation in a real urban scenario confirms the system's effectiveness in improving VRU safety.

II.LiteratureSurvey

Recent research has explored various approaches to enhance VRU safety. Multi-sensor fusion techniques using cameras, radar, and LiDAR have shown significant improvements in detection accuracy. Vehicle-to-Pedestrian (V2P) communication systems using DSRC, LTE, and 5G enable real-time alerts between vehicles and VRUs.

Studies on cooperative Intelligent Transport Systems (C-ITS) and V2X communication highlight the benefits of integrating vehicle, pedestrian, and infrastructure data. AI-based

behavior prediction models (including deep learning and Transformer architectures) have been used for crossing-intention detection. Smartphone-based solutions leveraging accelerometer and gyroscope data have achieved high activity-recognition accuracy. Infrastructure-based roadside units (RSUs) and edge-computing approaches further reduce latency in urban environments.

However, most existing solutions rely on isolated technologies (sensor-only or communication-only) and lack full integration of sensing, communication, and computing. The proposed framework addresses this gap by providing an end-to-end, multi-modal, low-latency system specifically designed for real-world VRU protection.

III. Existing System & Proposed System

A. Existing System

Current VRU safety solutions primarily use either in-vehicle sensors, smartphone-based applications, or roadside infrastructure systems. These approaches typically rely on single-sensor detection or basic V2P communication and lack comprehensive data fusion across vehicles, VRUs, and smart-city infrastructure.

Disadvantages of Existing Systems:

1. Limited detection accuracy due to single-sensor reliance.
2. High latency in cloud-only processing.
3. Poor performance in adverse weather or low-visibility conditions.
4. Lack of real-time multi-party communication (vehicle-VRU-infrastructure).
5. Inability to predict collisions proactively.
6. High dependency on centralized servers.

B. Proposed System

The proposed system integrates multi-source sensing (vehicles, VRUs, roadside infrastructure), multi-technology communication (ITS-G5, C-V2X, 5G), and intelligent computing (sensor fusion + collision-prediction algorithms). Data is processed at both edge and cloud layers for optimal latency and accuracy. The system predicts potential collisions and issues immediate warnings to drivers and VRUs via their devices.

Advantages of the Proposed System:

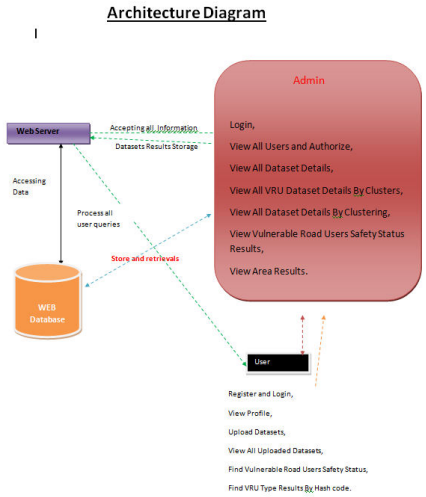
1. Real-time multi-sensor fusion for high detection accuracy.
2. Low-latency prediction using edge computing and 5G.
3. Proactive collision warnings to both vehicles and VRUs.
4. Hybrid communication support (ITS-G5 + 5G + multihoming).
5. Scalable for smart-city deployment.
6. Proven effectiveness in real-world urban testing.

IV. System Design & Architecture

A. System Architecture

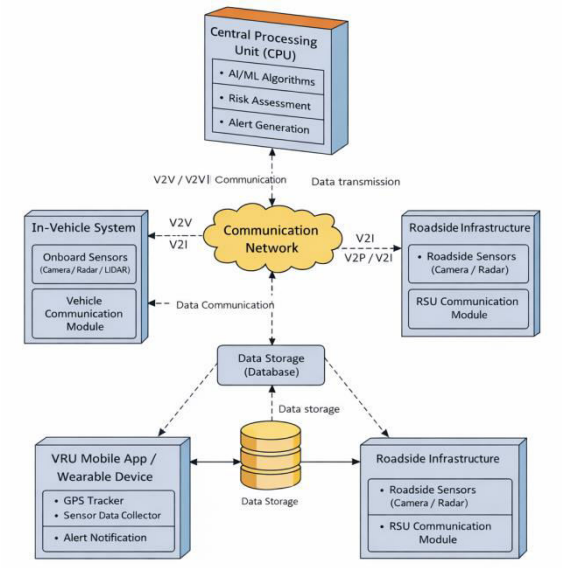
The architecture comprises three main layers: Sensing Layer (OBUs, VRU devices, roadside sensors), Communication Layer (ITS-G5, C-V2X, LTE, 5G), and Computing Layer (edge nodes + cloud server). Data flows from

sensors → fusion engine → collision-prediction algorithm → warning dissemination.



B. System Flowchart

User/VRU registration → real-time data collection from sensors/devices → multi-sensor fusion → collision risk assessment → immediate alert generation → notification to driver and VRU via mobile/OBU.



C. Modules Overview

1. **Sensing Module**: Collects data from vehicle OBUs, VRU smartphones/wearables, and roadside cameras/radars/LiDARs.
2. **Communication Module**: Handles multi-technology data exchange (ITS-G5, C-V2X, 5G).
3. **Data Fusion & Prediction Module**: Performs sensor fusion and runs kinematics-based collision-detection algorithms.
4. **Alert & Notification Module**: Generates and delivers real-time warnings.

5. **Edge-Cloud Computing Module**: Optimizes processing latency and scalability.

Table I: Technology Stack

Component	Technology / Tool
Programming Language	Java / J2EE
Sensing Technologies	Cameras, Radar, LiDAR, Smartphone Sensors
Communication	ITS-G5, C-V2X, LTE, 5G
Computing Platform	Edge Computing + Cloud Server
Database	MySQL
Web Framework	JSP / Servlets
Simulation / Testing	Real-world urban testbed (Aveiro Tech City)
Operating System	Windows / Linux (cross-platform)

Table II: Performance / Evaluation Summary

Metric / Component	Proposed System	Existing Systems	Remarks
Prediction Accuracy	High	Moderate	Multi-sensor fusion
Latency	Very Low (edge + 5G)	High	Real-time alerts
Detection Reliability	Excellent (all weather)	Poor in adverse conditions	Robust sensor fusion
Scalability	High	Limited	Smart-city ready
Communication Support	Multi-technology (ITS-G5 + 5G)	Single technology	Hybrid & multihoming
Collision Warning Time	Proactive (before impact)	Reactive	Kinematics-based prediction

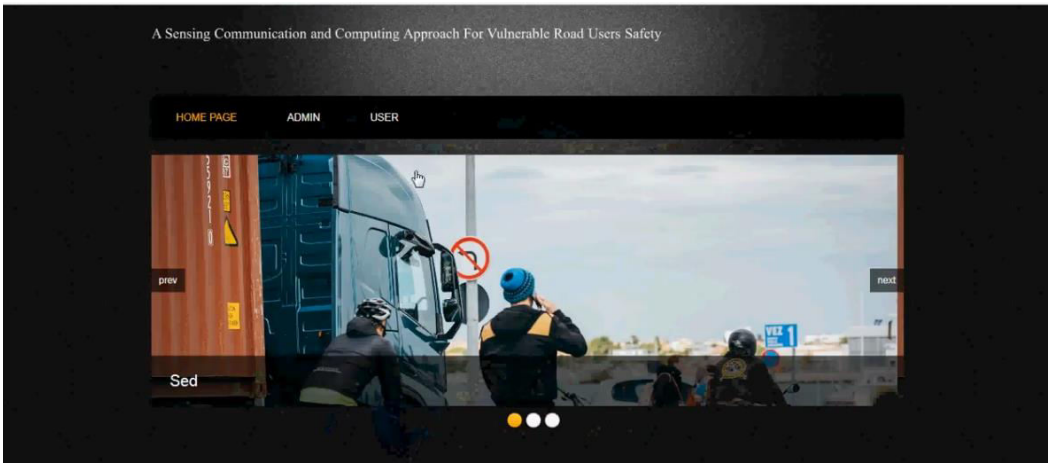
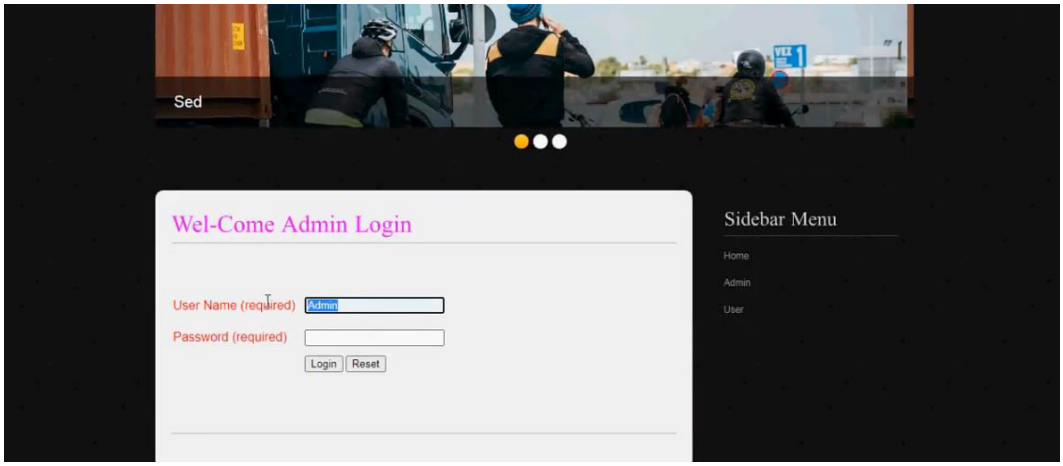


Fig1: home Page



Figv2: Admin login page

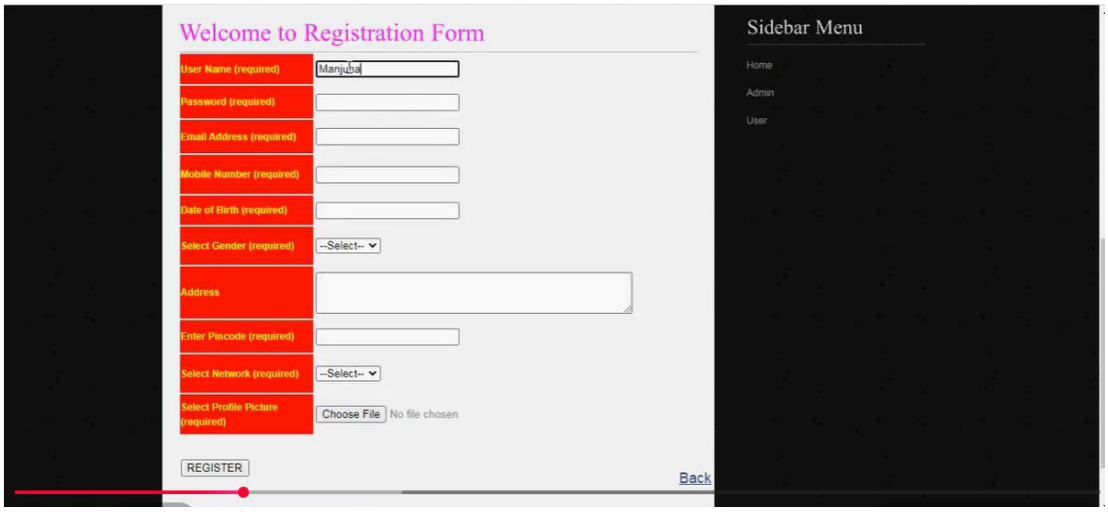


Fig3: user Registration page

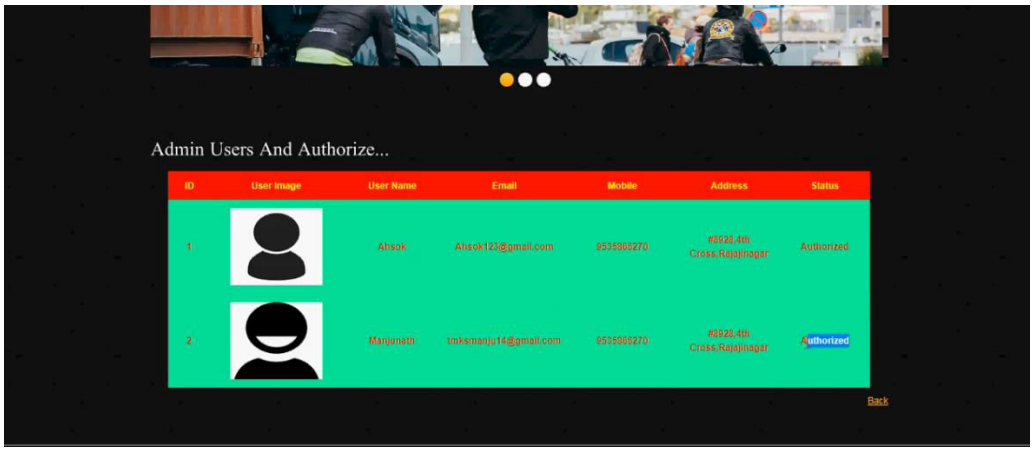


Fig 4: Admin Authorize page

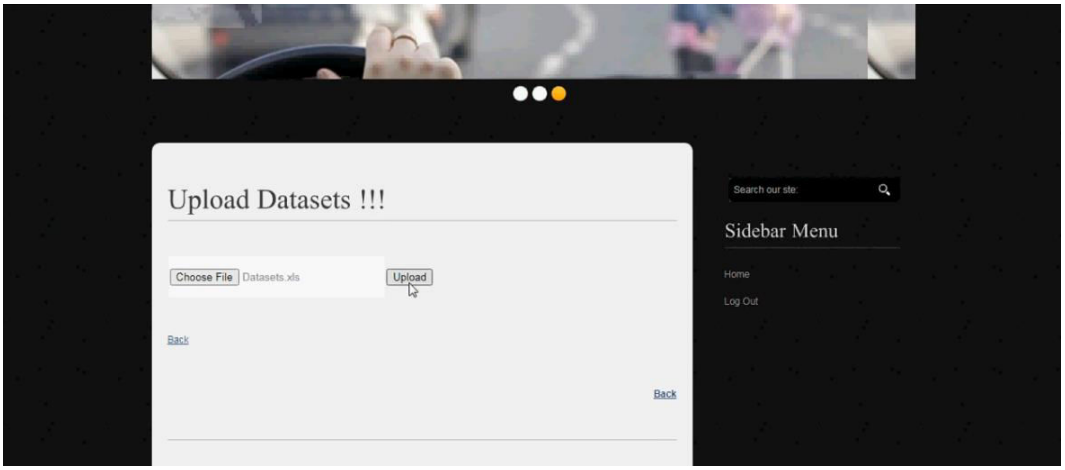


Fig 5: File Upload

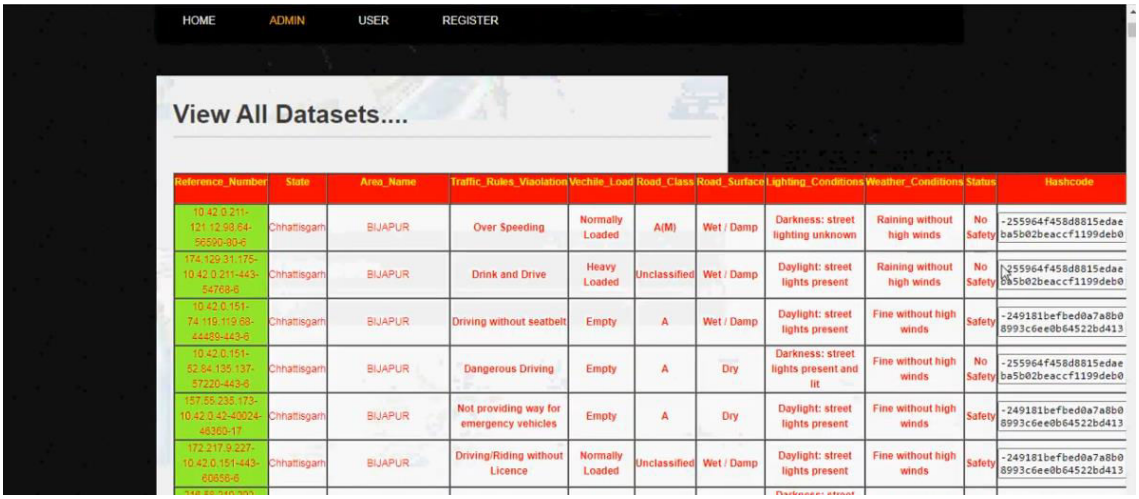


Fig 6: View all uploaded dataset by admin

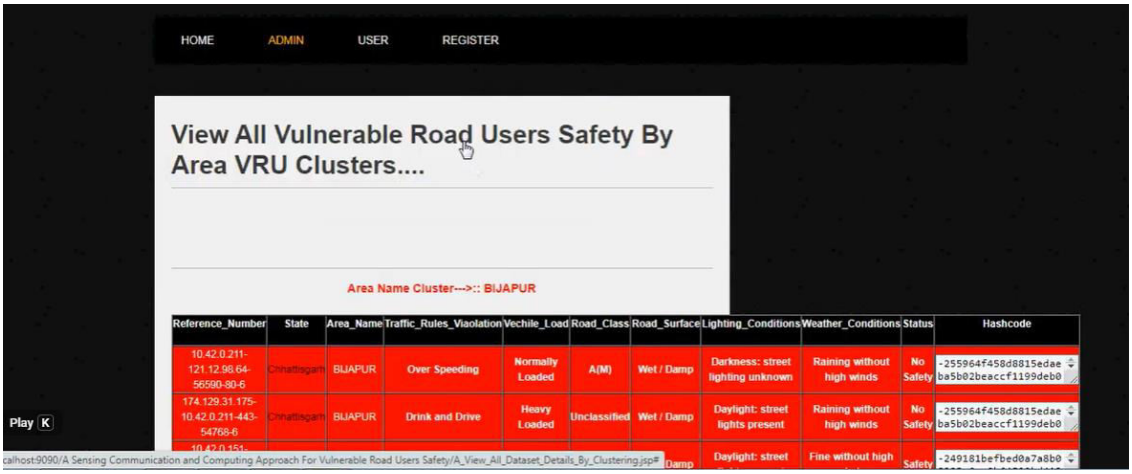


Fig 7: vunarable road safety users

VI. Conclusion

This paper presented a sensing, communication, and computing framework for protecting Vulnerable Road Users in smart cities. By integrating multi-source sensors, hybrid communication technologies, and edge-cloud computing, the system achieves accurate, low-latency collision prediction and proactive warnings. Real-world testing confirms its effectiveness and highlights the critical role of 5G and edge computing for future intelligent transportation systems. The proposed approach provides a scalable and reliable solution for enhancing VRU safety in urban environments.

Future Enhancement

Integration of advanced AI models (Transformers, deep learning for behavior prediction), support for additional VRU types (e-scooters, elderly users), incorporation of environmental awareness (weather/lighting adaptation), and large-scale smart-city deployment with V2X and autonomous vehicle integration.

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