Integrated Smart Accident Management System for Urban Traffic Congestion Alleviation and Improved Road Safety

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Abstract: Global urbanization and increased population mobility have led to a surge in vehicular traffic, posing challenges in effective traffic management, and resulting in congestion, accidents, and pollution. Despite advancements, accidents persist as a major cause of mortality, highlighting the need for a unified accident management system. Real-time route planning offers promise but faces challenges in accounting for diverse driver preferences. This proposed technique leverages smart technology to enable real-time communication among vehicles, ambulances, hospitals, roadside units, and central servers, optimizing road network utilization and reducing vehicle congestion. This paper introduces an accident detection system utilizing fuzzy logic to identify accidents, enhancing traffic flow management, thereby improving road safety and potentially saving lives.

Motivation: The motivation behind this work stems from the urgent need to address the escalating challenges posed by increasing vehicular traffic in urban areas. With the expansion of cities and rising population mobility, traffic congestion, accidents, and pollution have become significant issues. Despite advancements in traffic management systems and vehicle technologies, road accidents continue to be a leading cause of mortality. Hence, there is a critical need for an integrated accident management system that can effectively manage road traffic and enhance road safety.

Novelty: The novelty of this work lies in proposing an innovative approach to accident management and traffic flow optimization using smart technology and fuzzy logic. While previous studies have explored various techniques for automatic accident detection, the integration of fuzzy logic into the accident detection system represents a novel approach. Fuzzy logic allows for the incorporation of linguistic variables, membership functions, and rule sets, enabling more nuanced decision-making in real-time traffic management. Additionally, the proposed system facilitates communication among vehicles, ambulances, hospitals, roadside units, and central servers, creating a comprehensive framework for accident management and traffic flow optimization.

Findings: Through the implementation of the proposed accident management system, the study finds significant improvements in road safety and traffic congestion mitigation. By leveraging real-time communication and fuzzy logic-based decision-making, the system effectively detects accidents along roads and facilitates traffic flow optimization. The findings demonstrate the potential of smart technology and fuzzy logic in enhancing road safety, reducing travel costs, and potentially saving lives. Moreover, the study highlights the importance of integrating advanced technologies into traffic management systems to address the challenges posed by urban traffic congestion and road accidents effectively.

***Keywords**: fuzzy logic controller, vehicle module, driver module, Fuzzy logic, linguistic variables, membership function, accident detection*

1. Introduction

Urban areas around the globe are witnessing unprecedented growth, accompanied by a surge in population mobility and vehicular traffic. This rapid urbanization has led to a myriad of challenges, foremost among them being the management of traffic congestion [1]. Traffic congestion, characterized by the slowdown or halt of vehicles on roadways due to excessive demand, is a pervasive issue in urban environments [2]. It arises from various factors such as population density, inadequate transportation infrastructure, and inefficient traffic management systems [3-4]. It also increases the likelihood of accidents, leading to significant societal and economic repercussions [5]. Additionally, the rise in traffic congestion contributes to heightened pollution levels, further impacting the quality of life in urban areas.

The consequences of traffic congestion extend far beyond mere inconvenience for commuters. It engenders a host of adverse effects, including increased travel time, heightened air pollution levels, and elevated risks of road accidents [6]. Despite advancements in traffic management technologies and strategies, [7-8] suggested that accidents remain a significant concern, posing threats to public safety and resulting in considerable economic losses.

Efforts to mitigate the impacts of traffic congestion and improve road safety have spurred the development of innovative solutions, one of which is the integration of smart accident management systems. These systems leverage cutting-edge technologies such as real-time communication networks, vehicle sensors, and intelligent algorithms to detect and respond to accidents swiftly and effectively. Authors in [9] proposed that among the methodologies employed in accident detection, fuzzy logic control is better as it offers a flexible and adaptable approach to decision-making in complex and uncertain environments.

This paper explores the design and implementation of an Integrated Smart Accident Management System aimed at alleviating urban traffic congestion and enhancing road safety. Building upon the principles of fuzzy logic control, the system integrates various components to enable real-time accident detection, emergency response coordination, and traffic flow optimization. By leveraging advanced technologies and innovative strategies, this integrated system seeks to address the multifaceted challenges posed by urban traffic congestion while improving overall road safety and efficiency.

By integrating advanced technologies such as real-time communication networks, vehicle sensors, and intelligent algorithms, the proposed system contributes some key factors to address the complex challenges posed by urban traffic congestion and road safety.

- The system facilitates swift and accurate detection of accidents through advanced sensor technologies and intelligent fuzzy algorithms which enables prompt emergency response and enhances overall road safety.
- Through the implementation of traffic management strategies, the system optimizes traffic flow in urban areas, reducing congestion and travel times for commuters. This contributes to improved efficiency and mobility within the transportation network.
- By integrating various components such as environmental conditions study, driver health monitoring, vehicle condition assessment, and proactive response mechanisms, the system enhances overall road safety by identifying potential hazards and mitigating risks in real time.
- The system's ability to optimize traffic flow and mitigate accidents translates into cost savings in the form of reduction in fuel consumption, travel times, and the frequency of accidents.
- Six different parameters like fog & rainfall (Environmental parameters), pulse rate & blood pressure (Driver health parameters), and noise & heat (vehicle parameters) are used to estimate the occurrence of accidents.

2. Literature Survey

Urban traffic congestion management and road safety enhancement are critical areas of research, given the increasing challenges posed by growing urbanization and vehicular traffic. Within this domain, fuzzy logic-based accident detection systems have emerged as promising solutions to address the complexities of urban traffic management and improve road safety. This literature review explores existing research and studies in this field, focusing on the significance of fuzzy logic-based approaches in accident detection and traffic management.

Fuzzy logic, a computational paradigm that deals with uncertainty and imprecision, has gained traction in accident detection systems due to its ability to model complex relationships and make decisions based on vague or ambiguous input data [10]. Several studies have demonstrated the effectiveness of fuzzy logic in enhancing accident detection accuracy and response time.

Authors [11] proposed a fuzzy logic-based accident detection and alert system that utilizes fuzzy inference rules to analyze real-time traffic data and identify abnormal patterns indicative of accidents. By integrating fuzzy logic with vehicle sensor data, the system achieved high accuracy in accident detection, enabling prompt response and mitigation measures. Similarly, [12] introduced a real-time traffic congestion detection and control system based on image processing and fuzzy logic, showcasing its effectiveness in mitigating congestion and improving traffic flow.

Moreover, [13] developed a fuzzy logic-based accident detection and alert system tailored for urban traffic management. By integrating fuzzy inference rules with real-time traffic data, the system achieves high accuracy in identifying potential accident scenarios, enabling prompt response and mitigation measures. Building upon these advancements, [14] proposed a dynamic traffic congestion detection and control system utilizing fuzzy logic and machine learning techniques. By adapting traffic signal timings and route assignments in response to changing traffic conditions, the system demonstrated its efficacy in reducing congestion and enhancing road safety in urban environments. Furthermore, [15] introduced a fuzzy logic-based adaptive traffic signal control system for urban traffic management. By incorporating fuzzy inference mechanisms and adaptive control strategies, the system dynamically adjusts traffic signal timings based on real-time traffic flow data, thereby optimizing traffic flow and reducing congestion. These studies collectively highlight the potential of fuzzy logic-based approaches in developing advanced accident detection systems for urban traffic management, contributing significantly to alleviating traffic congestion and improving road safety in urban environments.

Although literature exists on various strategies for accident detection and prevention, there is a notable absence of a comprehensive survey. This paper aims to bridge this gap by critically reviewing the literature on accident detection, prevention, and reporting systems. By offering a broader perspective on existing techniques, the goal is to facilitate the development of effective systems that leverage strengths while addressing challenges within current systems.

The remainder of this article is organized as follows: Section II delves into a survey of the literature behind this work; Section III explores the objective of the work; Section IV discusses the proposed work; Section V provides the results and their analysis; and finally, Section VI concludes the paper.

3. Objectives

The objective of this proposed work is to develop and implement an efficient and integrated accident management system applying smart technology and fuzzy logic. The primary goals include:

1. The system aims to reduce the number of road accidents and associated fatalities by implementing real-time accident detection mechanisms and facilitating timely response from emergency services.
2. By optimizing traffic flow through real-time route planning and coordination among vehicles, ambulances, hospitals, and central servers, the system seeks to alleviate traffic congestion on urban roads.
3. Applying advancements in smart technology, the system aims to improve communication and coordination among various stakeholders involved in accident management, including drivers, emergency services, and traffic authorities.
4. The incorporation of fuzzy logic into the accident detection and traffic flow optimization processes enables more nuanced decision-making, considering diverse driving conditions, preferences, and uncertainties.
5. The objective is to develop a comprehensive framework for accident management and traffic flow optimization, utilizing real-time data and intelligent algorithms to enhance the efficiency of urban transportation systems.

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4. Proposed work

The architecture of the proposed system is shown in Fig.1, which has three major units referred to in this work the vehicle module, the Server/Central Control Unit, and a group of nearby hospitals referred to as hospital modules.

The vehicle module consists of sensor units and a local processor referred to as an on-board unit. These two units are responsible for different tasks such as monitoring various sensors, detecting accidents through a fuzzy logic controller, and communicating messages to the nearby units. In case of an accident, the on-board unit sends an alert message to a Central Control Unit. The Central Control Unit takes care of ambulance movements to the hospitals through the shortest route. Nearby hospitals are identified through Google Maps and depending on the traffic congestion level, the ambulances reach the accident place as well as the nearby hospital quickly. The ambulance nearest to the vehicle gets connected to a nearby hospital and continuously sends the health condition of the patient, hence reducing the delay time in treatment. The emergency module is connected to both the ambulance as well as to the central control unit.

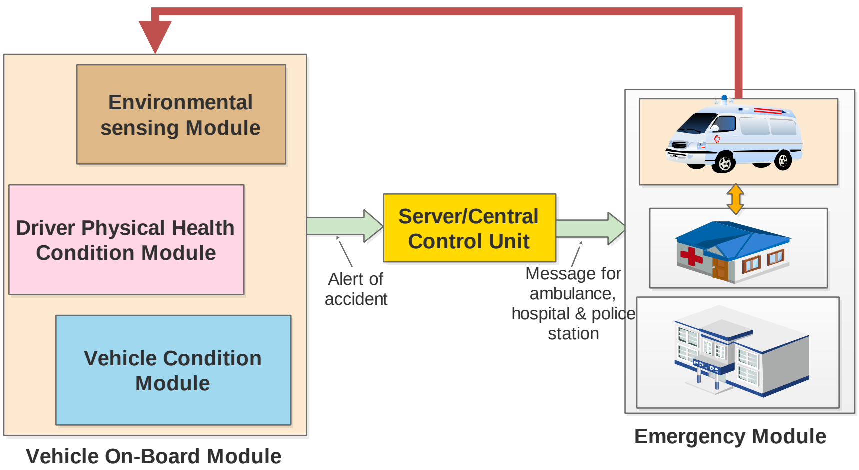


Fig. 1 Architecture of the Proposed System

4.1 Selection of Sensors and Other Hardware

For accident detection, sensors are integrated with the on-board unit (OBU) of each of the vehicles to sense the vehicle condition, driver's physical health condition, and environmental condition. The details of sensors used for checking the conditions of vehicles and travelers are discussed below.

1. ***Sensors for the detection of environmental condition***

The fog sensor and rainfall sensor are used to know the occurrence of fog and rainfall which explains the environmental condition during an accident.

2. ***Sensors for detection of driver's physical condition***

The pulse sensor and blood pressure sensor are used to identify the physical conditions of travelers in the vehicle. The pulse and blood pressure sensors are fixed to the seat belt to measure these parameters easily. These sensor outputs are processed in the processor of the OBU.

3. ***Sensors for detection of Vehicle condition***

The sensors, which are used to find the condition of the vehicle, are a noise sensor to detect noise after an accident, and a heat sensor to detect the heat generated after an accident. These sensor outputs are processed in the processor of the OBU.

4. ***Processing of Sensor Data***

The small processor on the on-board unit of the vehicle as shown in Fig.2 takes data from these sensors and processes them through a Mamdani Fuzzy Logic controller based on fuzzy logic decision support that uses these input variables from sensors such as noise sensor, heat sensor, pulse sensor, blood pressure sensor, fog sensor, and rainfall sensor to detect an accident. Each of these variables has different ranges, to create different combinations of inputs for accidents.

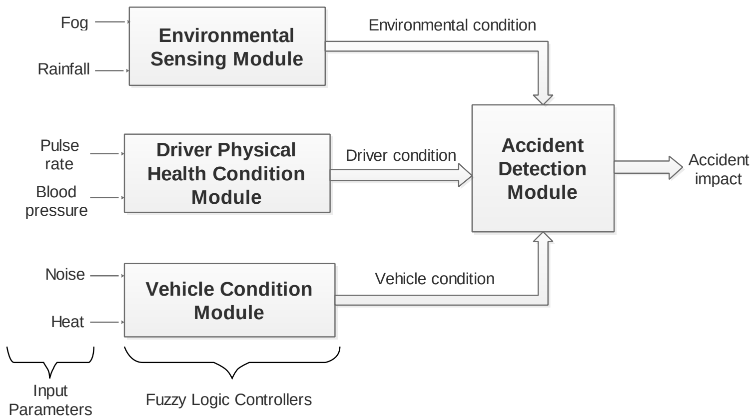


Fig.2 On-board unit (OBU) present in the vehicle

4.2 Fuzzy Logic Detection Support

It is included in the on-board unit of the vehicles to evaluate the occurrence of an accident. It uses statistical reasoning with borderline values. A Simulink model is constructed and operated by using these individual fuzzy logic controllers with different inputs. This decision support is based on a Mamdani Fuzzy Logic controller, which uses six input variables such as noise, heat, blood pressure, pulse rate, fog, and rainfall.

The proposed work involves the integration of a fuzzy logic controller (FLC) as a key component to enhance accident detection, traffic flow management, and road safety in urban environments. The FLC will serve as the decision-making mechanism within the system, utilizing fuzzy inference rules to analyze real-time input condition information and make intelligent decisions. Fig.3 shows the details of a general FLC.

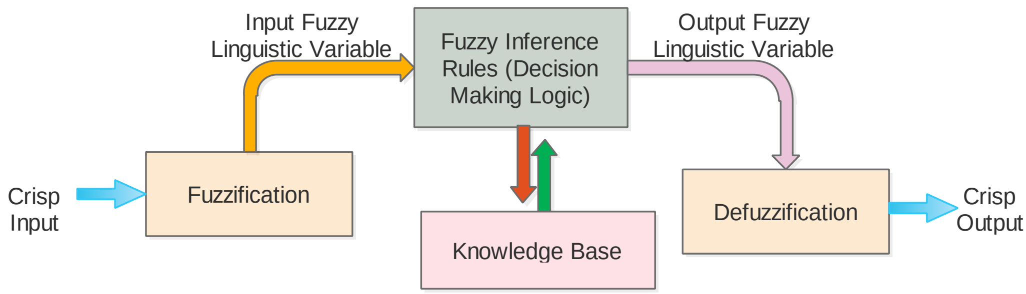


Fig.3 Block diagram of a generalized FLC

Linguistic variables along with corresponding membership functions, encode qualitative input data into fuzzy sets, facilitating the representation of uncertainty and imprecision. Fuzzy inference rules encapsulate domain knowledge and system heuristics, dictating the system's response based on the current state of input variables. These rules, stored in the rule base, guide the FLC in generating appropriate actions to address the challenges. Through the fuzzy inference process, which entails fuzzification, rule evaluation, and defuzzification, the FLC translates fuzzy input data into crisp output actions, enabling the system to dynamically adapt and react to changing output conditions. Ultimately, the FLC empowers the system to make informed decisions, optimize output, and enhance output conditions by leveraging the flexibility and robustness of fuzzy logic principles.

4.3 *Membership functions and fuzzy rules*

4.3.1 *Environment Sensing Module*

The two inputs to the environment sensing module are from the sensors: fog sensor and rainfall sensor. The specifications of the triangular membership function (MF) taken to express the visibility in fog, rainfall, and output of the module i.e environmental effect on the accident are as follows:

(i) Fog (visibility range in m)
Range – Light_fog (180-400), Midium_fog (50-240), Dense_fog (0-65)
(ii) Rainfall(mm/hour)
Range – Low (0 - 0.5), Moderate (0.4 – 2.5), High (2 - 4)
(iii) Output (environment effect on the accident in percentage)
Range – Low (0 - 35), Moderate (30 - 70), High (60 - 100)

Fig.4 (a), (b), (c) shows the membership function (MF) of input and output parameters of the environment sensing module.

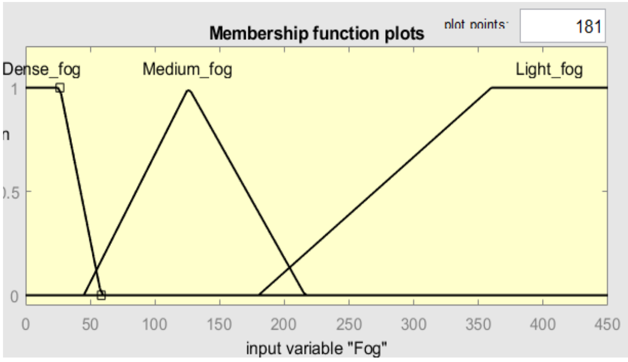


Fig. 4 (a) MF of the fog sensor

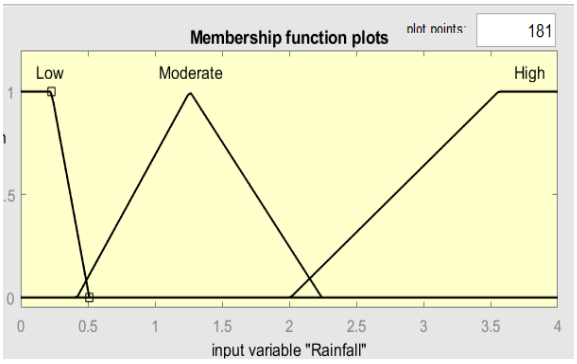


Fig. 4(b) MF of the rainfall detection sensor

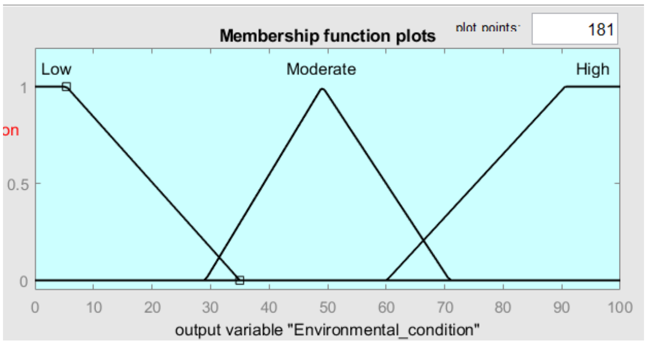


Fig. 4(c) MF of environment effect on accident

The fuzzy relationships between the inputs or states of fuzzy subsets on one side and the output of fuzzy subsets on the other side of FLC are expressed by the rule base. The fuzzy rules constructed for the environmental sensing module are expressed in Table 1.

Table 1: Fuzzy Rules for Environment Sensing Module

Fog	**Rainfall**	**Environment effect on accident**
Light Fog	Low	Low
Light Fog	Moderate	Moderate
Light Fog	High	High
Medium Fog	Low	Low
Medium Fog	Moderate	Moderate
Medium Fog	High	High
Dense Fog	Low	Moderate
Dense Fog	Moderate	High
Dense Fog	High	High

4.3.2 *Driver Physical Health Condition Module*

The two inputs to the driver's physical health condition module are from the sensors: pulse rate sensor and blood pressure sensor. The specifications of the triangular membership function (MF) taken to express the pulse rate, systolic blood pressure, and output of the module i.e driver's physical condition are as follows:

(i) Pulse rate (beats/minute)
Range – Low (50-70), Medium (60-100), High (90-120)
(ii) Systolic blood pressure (systolic hg/mm)
Range – Low (50- 80), Medium (75 - 130), High (120-160)
(iii) Output (Driver's physical health condition)
Range – Low (0 - 35), Medium (30 - 75), High (70 - 100)

Fig.5 (a), (b), (c) shows the membership function (MF) of input and output parameters of the driver's physical health condition.

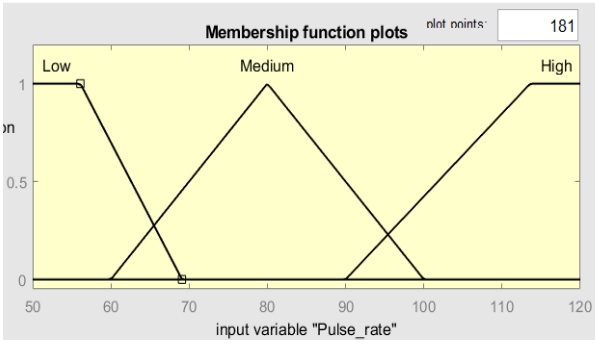


Fig 5. (a) MF of pulse rate sensor

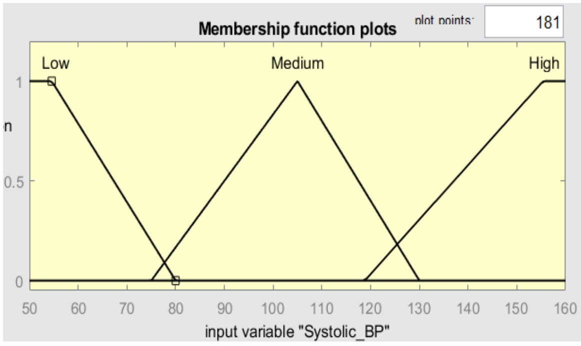


Fig 5. (b) MF of systolic blood pressure sensor

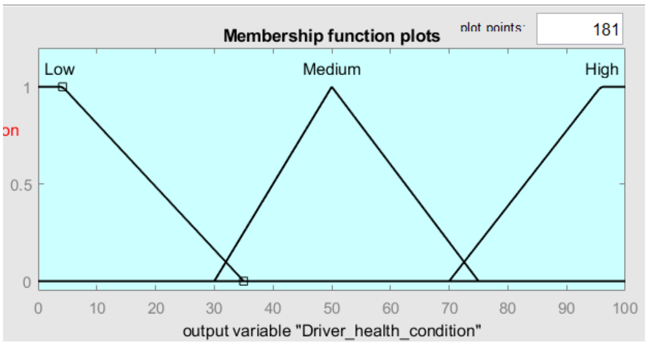


Fig 5. (c) MF of driver's physical health condition.

The fuzzy relationships between the inputs or states of fuzzy subsets on one side and the output of fuzzy subsets on the other side of FLC are expressed by the rule base. The fuzzy rules constructed for the driver's physical health condition module are expressed in Table 2.

Table 2: Fuzzy Rules for Driver's Physical Health Condition Module

Pulse rate	Systolic blood pressure	Driver's physical health condition effect on accident
Low	Low	High
Low	Medium	Medium
Low	High	High
Medium	Low	High
Medium	Medium	Medium
Medium	High	High
High	Low	High
High	Medium	High

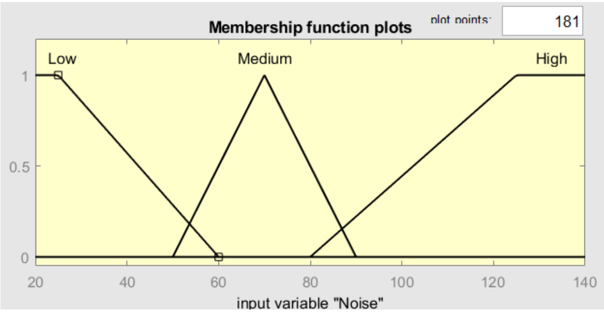
High	High	High

4.3.3 *Vehicle Condition Module*

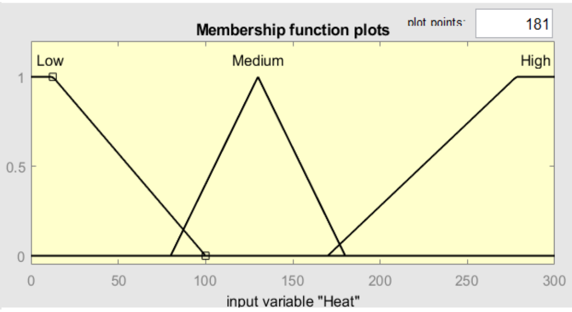
The two inputs to the vehicle condition module are from the sensors: noise sensor and heat sensor. The specifications of the triangular membership function (MF) taken to express the noise, heat, and output of the module i.e vehicle condition are as follows:

(i) Noise (dB)
Range – Low (20 - 60), Medium (50 - 90), High (80 - 140)
(ii) Heat sensor (degree C)
Range – Low (0 - 100), Medium (80 - 180), High (170-300)
(iii) Output (Vehicle condition)
Range – Low (0 - 35), Moderate (30 - 80), High (70 - 100)

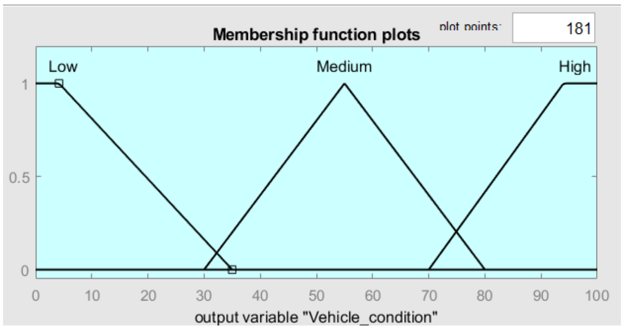
Fig.6 (a), (b), (c) shows the membership function (MF) of input and output parameters of the vehicle condition.



(Fig. 6(a) MF of Noise)



(Fig. 6(b) MF of Heat)



(Fig. 6(c) MF of Vehicle condition)

The fuzzy relationships between the inputs or states of fuzzy subsets on one side and the output of fuzzy subsets on the other side of FLC are expressed by the rule base. The fuzzy rules constructed for the vehicle condition module are expressed in Table 3.

Table 3: Fuzzy Rules for Vehicle Condition Module

Noise	Heat	Vehicle condition effect on accident
Low	Low	Low
Low	Medium	Low
Low	High	High
Medium	Low	Low
Medium	Medium	Medium
Medium	High	High
High	Low	Medium

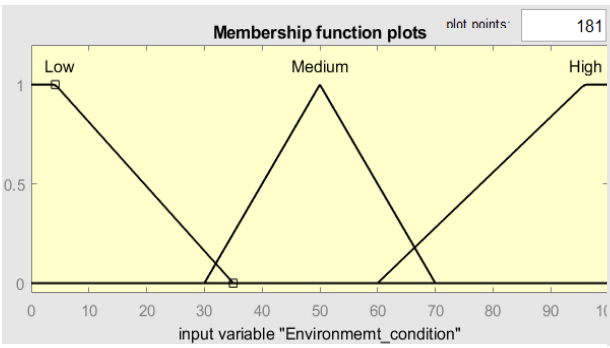
High	Medium	High
High	High	High

4.3.4 *Accident Detection Module*

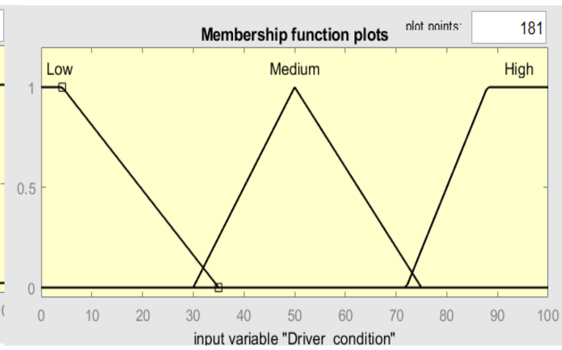
The three inputs to the accident detection module are from the modules: environment sensing module, driver physical health condition module, and vehicle condition module. The specifications of the triangular membership function (MF) taken to express the environment condition, driver condition, vehicle condition, and output of the module i.e accident impact are as follows:

(i) Environment condition (in percentage)
Range – Low (0 - 35), Medium (30 - 70), High (60 - 100)
(ii) Driver condition (in percentage)
Range – Low (0 - 35), Medium (30 - 75), High (70 - 100)
(iii) Vehicle condition (in percentage)
Range – Low (0 - 35), Moderate (30 - 80), High (70 – 100)
(iv) Output (Accident impact)
Range – Low (0 - 35), Moderate (30 - 80), High (70 - 100)

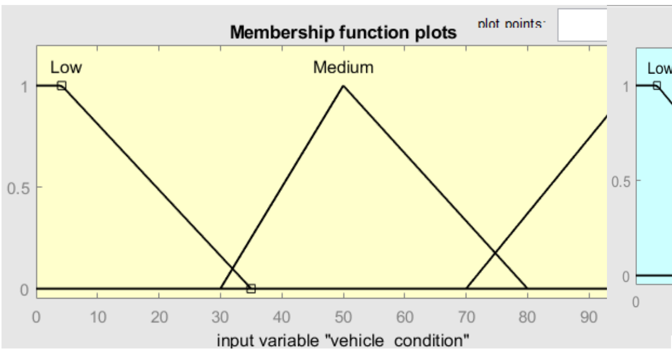
Fig.7 (a), (b), (c), and (d) shows the membership function (MF) of input and output parameters of the accident detection module.



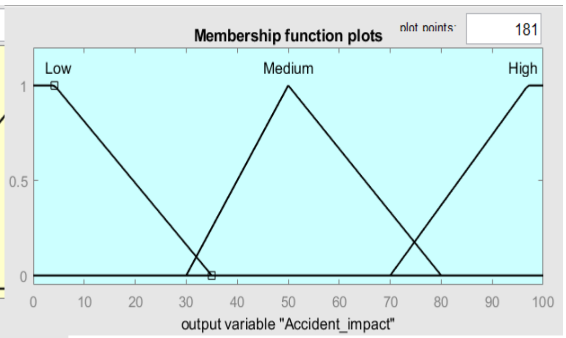
(Fig. 7(a) MF of Environment condition)



(Fig. 7(b) MF of Driver condition)



(Fig. 7(c) MF of Vehicle condition)



(Fig. 7(d) MF of Accident impact)

The fuzzy relationships between the inputs or states of fuzzy subsets on one side and the output of fuzzy subsets on the other side of FLC are expressed by the rule base. The fuzzy rules constructed for the accident detection module are expressed in Table 4.

Table 4: Fuzzy Rules for Accident Detection Module

Environment condition	Driver condition	Vehicle condition	Accident detection module
Low	Low	Low	Low
Low	Low	Medium	Low
Low	Low	High	Medium
Low	Medium	Low	Low
Low	Medium	Medium	Low
Low	Medium	High	Medium
Low	High	Low	Low
Low	High	Medium	Medium
Low	High	High	Medium
Medium	Low	Low	Low
Medium	Low	Medium	Medium
Medium	Low	High	Medium
Medium	Medium	Low	low
Medium	Medium	Medium	Medium
Medium	Medium	High	Medium
Medium	High	Low	Medium
Medium	High	Medium	High
Medium	High	High	High
High	Low	Low	Low
High	Low	Medium	Low
High	Low	High	Medium
High	Medium	Low	Low
High	Medium	Medium	Medium
High	Medium	High	High
High	High	Low	Medium
High	High	Medium	High
High	High	High	High

5. Result and Analysis

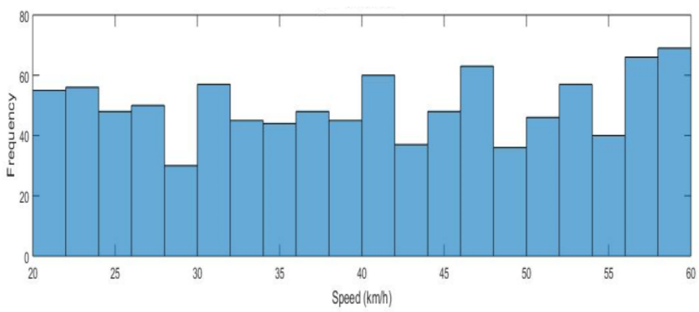


Fig. 8 (a) Occurrence of various vehicle speeds along the road

The vehicle speed along the road side detected by the proposed integrated smart accident management system are shown in the Fig. 8(a). Each bar in the histogram represents a range of speeds, while the height of the bars indicates the frequency of vehicles within each speed range. This visualization provides an overview of the typical distribution of vehicle speeds, which is crucial for understanding the traffic dynamics on the road

Fig.8 (b) depicts the variation in vehicle speeds along the road. Each point on the plot corresponds to the speed of a particular vehicle at a specific location along the road. If an accident is detected, it is indicated on the plot by a red cross, providing a visual reference for the location of the incident. This plot offers insight into the spatial distribution of vehicle speeds and allows for the identification of potential congestion or abnormal traffic patterns, especially when coupled with real-time monitoring and analysis.

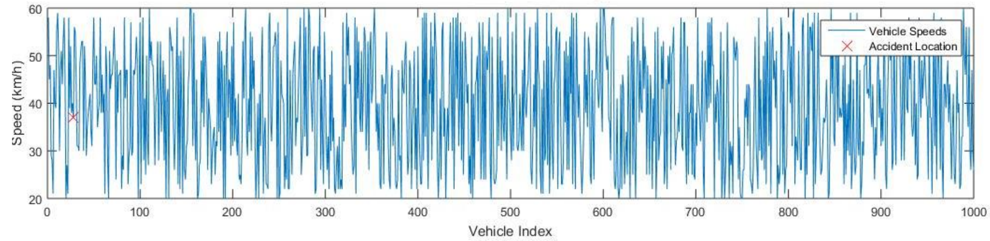


Fig.8 (b) Variation of vehicle speed and occurrence of accident

The surface plots are analyzed using the fuzzy logic toolbar for each of the controllers used in the proposed model. It is a pictorial representation of the fuzzy rule table mentioned in Tables 1, 2, 3, and 4. The surface plots of each of these controllers are shown in Fig. 9(a), (b), (c), and (d).

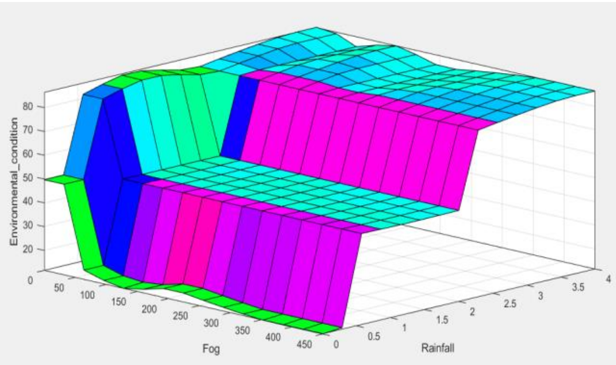


Fig. 9(a) Surface plot of Environmental condition

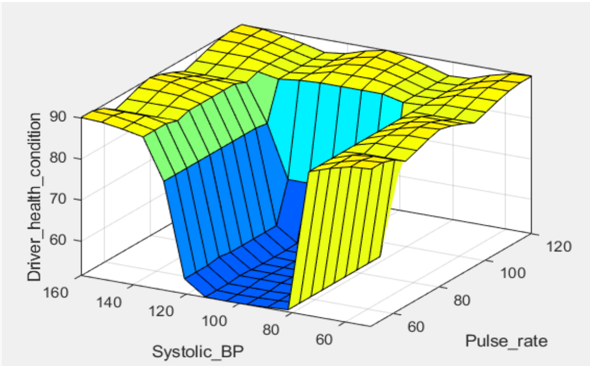


Fig. 9(b) Surface plot of Driver health condition

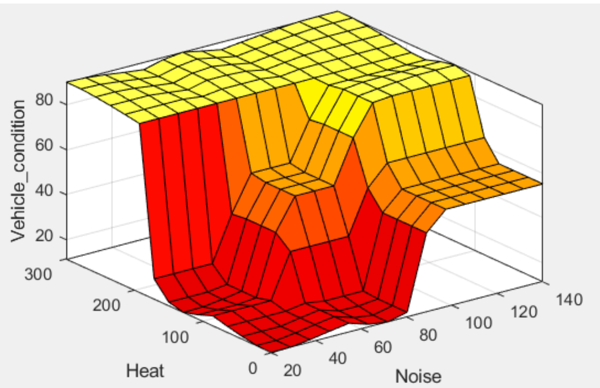


Fig. 9. (c) Surface plot of Vehicle condition

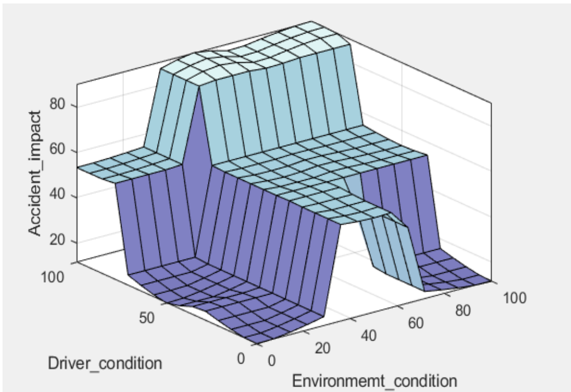


Fig. 9(d) Surface plot of Accident impact

The Simulink model of the proposed work is constructed and operated using input/output variables and fuzzy logic controllers. The model is presented in Fig. 10. This model confirms the chance of an accident based on a Fuzzy Rule-based system. The fuzzy rules for the detection of environmental conditions, driver condition, and vehicle condition are taken from the Tables 1, 2, 3, and 4 respectively.

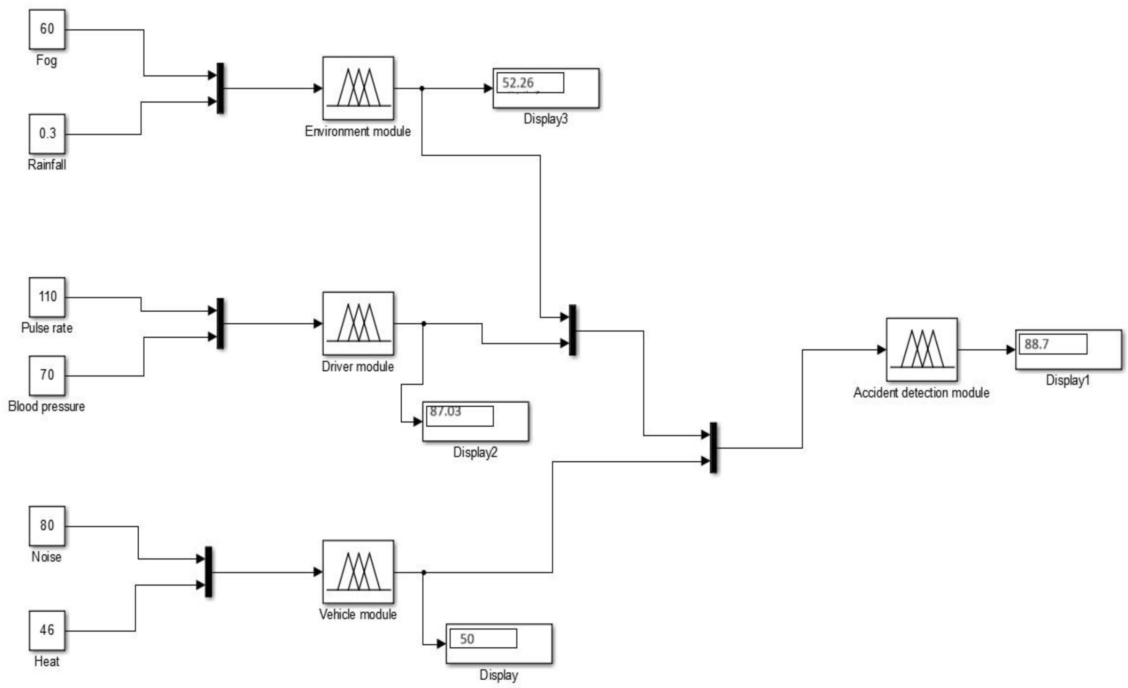
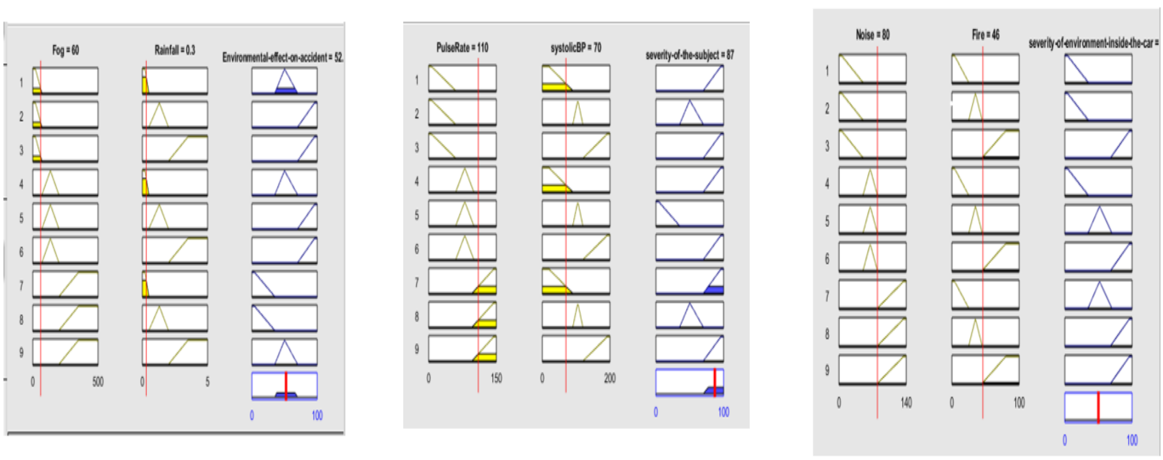


Fig.10 Simulink representation of the proposed model

5.1 Rule Viewer Analysis

The Rule Viewer allows interpreting the entire fuzzy inference process at once. The rule viewer shows how the shape of certain membership functions influences the overall result. Since it plots every part of every rule, it performs well for a small number of inputs and outputs.

Fig.11 (a) shows the response of the Environment Condition Fuzzy Logic Controller using Rule Viewer. When the fog in the environment is 60m visibility and rainfall is 0.3mm, the environment condition is 52.3% worse. Fig.11 (b) shows the response of the Driver Condition Fuzzy Logic Controller using Rule Viewer. For the driver, when the pulse rate is 110 beats/min and systolic blood pressure is 70 mm of mercury (mmHg), the driver's condition is 87% worse. Fig.11 (c) shows the response of the Vehicle Condition Fuzzy Logic Controller using Rule Viewer. When the noise after an accident in the vehicle is 80dB and temperature of the heat generated in vehicle after accident is 46^{0}C, then the vehicle condition is 50% worse.

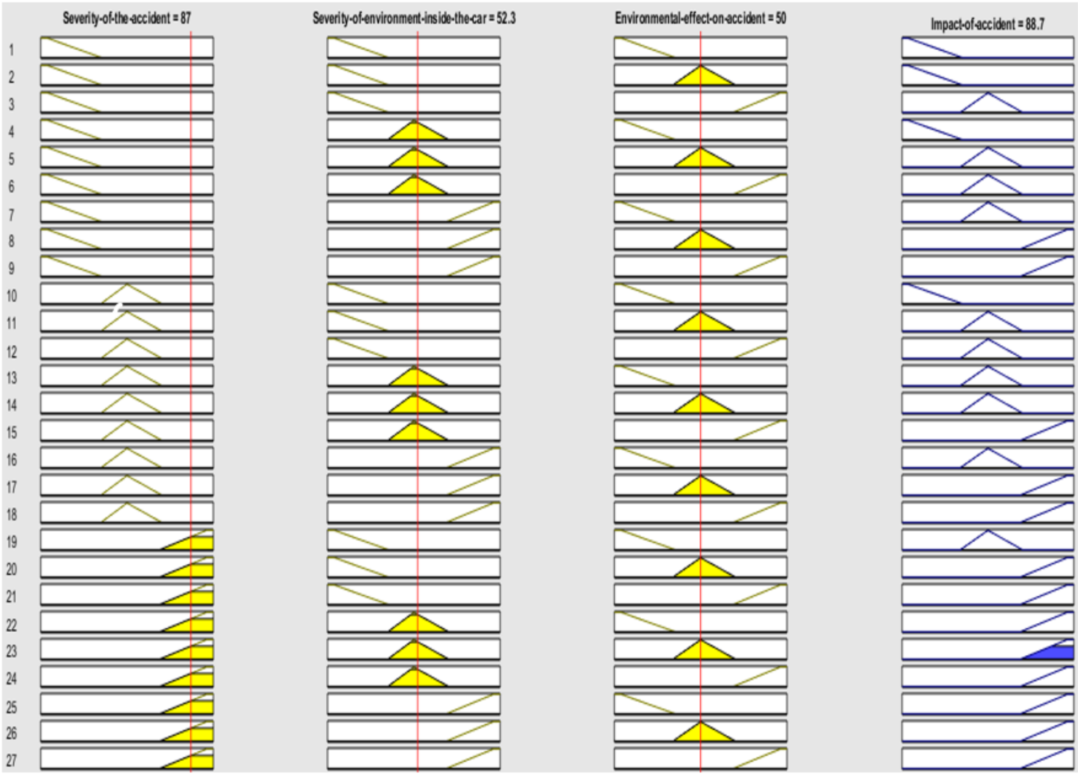


(Fig.11. (a) Rule viewer of Effect on environment)

(Fig.11. (b) Rule viewer of severity of the driver)

(Fig.11. (c) Rule viewer of vehicle condition)

5.2 Overall Impact of Accident



(Fig.12 Overall chance of accident)

Fig.12 shows the overall response of the Accident detection fuzzy logic controller using Rule Viewer. When the environmental condition is 52.3% worse, the driver condition is 87% worse, and the vehicle condition is 50% worse, then the accident chance is 88.7%.

6. Conclusion

The escalation of the global population contributes to a surge in vehicular traffic, exacerbating congestion on roads. Despite advancements in traffic management techniques, delays in accessing medical services during accidents remain a critical issue, often resulting in tragic consequences. To address this challenge, the development of an intelligent accident detection system becomes paramount. In this proposed work, fuzzy logic technology is used which encompasses vital functionalities such as accident detection, monitoring of victim parameters, and the message to ambulances, hospitals, police etc. This algorithm applies fuzzy logic to calculate the factor reflecting the relation between the occurrence of traffic accidents and environmental condition, driver condition & vehicle conditions and uses fuzzy logic controller to combine the traffic parameters along with the environment, driver and vehicle factors to detect the occurrence of accidents. By swiftly alerting authorities and facilitating immediate medical aid, this technique will minimize response times and increase the likelihood of saving lives. This integrated approach underscores the significance of proactive measures in enhancing road safety and emergency response capabilities in urban environments.

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