Integrated IoT-Driven System with Fuzzy Logic and V2X Communication for Real-Time Speed Monitoring and Accident Prevention in Urban Traffic

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***Abstract*—Road safety is a critical concern globally, with speeding being a leading cause of traffic accidents. Leveraging advanced technologies can significantly enhance the ability to monitor and control vehicle speeds in real time. Traditional methods of speed monitoring are often limited in their ability to provide real-time, adaptive interventions. Existing systems do not adequately integrate sensor data and decision-making processes to prevent speeding-related accidents effectively. This paper aims to address these limitations by proposing a novel system that utilizes Internet of Things (IoT) technology combined with fuzzy logic to monitor vehicle speeds and prevent accidents in real time. The proposed system integrates IoT sensors for continuous vehicle speed monitoring and employs a Fuzzy Inference System (FIS) to make decisions based on variables such as speed, alcohol presence, and driver fitness. The system also facilitates interaction between drivers and law enforcement through Vehicle-to-Everything (V2X) communication. The FIS implementation demonstrated effective speed control capabilities, accurately assessing and responding to various risk levels, thereby reducing the likelihood of speeding-related accidents. This research contributes to the advancement of road safety systems by integrating IoT and fuzzy logic technologies, offering a more adaptive and responsive approach to traffic management and accident prevention. Future enhancements will focus on incorporating machine learning techniques to dynamically adjust FIS rules based on real-time data and improve sensor network reliability to ensure more accurate and comprehensive monitoring.**

Keywords*—Internet of Things; high-speed monitoring; alcohol detection; Matlab simulation; write fuzzy inference system

I. Introduction

The Internet of Things (IoT) represents a collection of smart technologies and connected devices that are highly intelligent. IoT enables data exchange over a network without requiring human-to-human or human-to-computer interactions. This technology has made our daily tasks easier and smarter. IoT has been applied in various fields, such as electricity, gas, water, and transportation. In Bangladesh, the majority of the population relies heavily on road transportation. Currently, traffic accidents are a significant problem, with high-speed driving being the primary cause.

The alarming rate of traffic accidents in Bangladesh, primarily due to high-speed driving, underscores the need for an effective solution. Implementing a system to monitor and control vehicle speeds can significantly reduce the incidence of road accidents. Our motivation stems from the desire to enhance road safety and protect lives by leveraging IoT technology.

The implementation of a vehicle speed monitoring and control system can have profound social impacts. By reducing the number of traffic accidents, we can save lives and prevent injuries, thereby improving the overall well-being of society. Moreover, safer roads contribute to a more efficient transportation system, which can have positive economic implications.

The primary objectives of this study are:

- To develop an IoT-based system for monitoring and controlling vehicle speeds.
- To reduce the rate of traffic accidents caused by high-speed driving.
- To enhance the communication between vehicles and control authorities for prompt intervention.

The statistics of fatalities in road accidents in Bangladesh are shown in Table I. To address the high rate of traffic accidents, a fixed vehicle speed should be enforced on the highways of Bangladesh. By controlling vehicle speeds, it is possible to reduce the accident rate. In this study, we have developed an IoT-based system to monitor and control vehicle speeds effectively. Often, vehicles exceed speed limits at the start of their journeys, which is a primary cause of road accidents. Our device monitors vehicle speeds and sends alerts to both the nearest police control room and the driver when overspeeding is detected. The mortality rate of road accidents in the last 8 years in Bangladesh (2015-2022) is shown in Fig. 1.

Each vehicle is equipped with a smart card/board that has a unique identification number. The device sends a message to the nearest police control room with the smart card/board

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TABLE I. STATISTICS OF FATALITIES IN ROAD ACCIDENTS (SOURCE: DAILY NEWSPAPERS OF BANGLADESH)

Sl. No.	Year	Number of Fatalities	Reason	Type of Vehicle
1	2015	6823	Excessive speed	Bus and Truck
2	2016	3412	Hazardous overtaking	Motorcycle and Van
3	2017	4284	Careless driving	Microbus and Rickshaw
4	2018	7221	Poor road construction	Motorbike and Jeep
5	2019	7855	Unfit vehicles	Truck and Covered Van
6	2020	5431	Pedestrian carelessness	Truck and Pickup Van
7	2021	6284	Drunk driving	Minibus and Microbus
8	2022	4587	Lack of footpaths	Pickup and Van

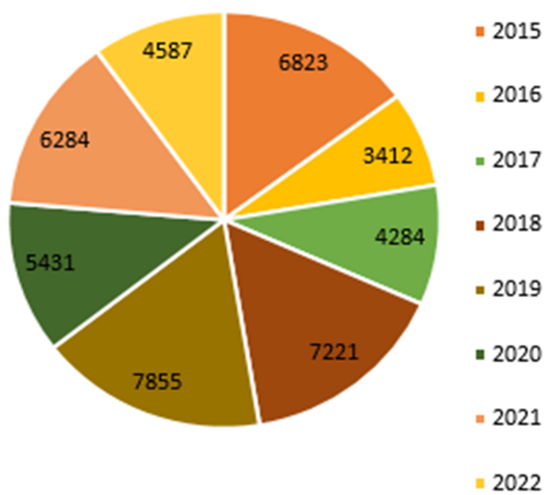

Fig. 1. Mortality rate of road accidents in the last 8 years in Bangladesh (2015-2022).

number when a vehicle is speeding. Simultaneously, it alerts the driver about the overspeeding. These devices are internet-enabled, allowing for monitoring and control.

The prevalence of road accidents globally, especially in developing countries like Bangladesh, is a critical concern. Bangladesh ranks among the highest in terms of accident rates. The primary cause of fatalities in accidents is the lack of emergency assistance. Timely intervention can save lives, making response time crucial. The vision of the Internet of Things (IoT) has rapidly expanded into new computing domains. IoT impacts human life more effectively and enhances functionality [1], [2].

The rest of the paper is organized as Section II discusses the previous works, Section III discusses the methodology, Section IV shows the implementation, Section V shows the results and discussion and finally Section VI shows the concluding remarks.

II. LITERATURE REVIEW

A. Related Works

Kishorkumar C. S. et al. proposed an intelligent car speed control system using Arduino and speed sensors. G. Kirankumar et al. developed an intelligent vehicle system for speed cameras using RuBee. Ravi Kishore Kodali et al. designed a system that enables traffic authorities to monitor all vehicles from the control room itself [3]. Sumit Deshpande et al. created a system that records the speed of vehicles and notifies relevant authorities of violations without human intervention [4]. P. Saichaitanya et al. proposed a car velocity tracking device using an accelerometer. Akriti et al. discussed the trade-offs in accidental control devices, including high costs and non-portability [5]. Chatrapathi et al. developed an efficient routing algorithm for ambulances [6]. Raut and Sachdev proposed a notification device using the XBee WiFi module, XBee Shield, and GPS module [7]. Ali and Alwan presented a device to detect low and high-speed vehicle crashes [8]. Aishwarya S. R. developed an approach that considered driver inconvenience [9]. Koneti S. et al. provided a solution for accidents caused by drunk driving [10]. Pratiksha R. et al. designed a device that detects accidents and monitors the car engine condition [11]. Kishwer K. et al. proposed an incident detection approach using sensors and hardware [12]. Namrata H. et al. implemented a push-button switch for boundary detection and microcontroller triggering [13]. Yadav et al. identified accidents and reported the reasons to registered numbers [14]. Reddy and Rao developed a system to detect vehicle fires and other failures [15]. Kavya and Geetha proposed a method to reduce delays caused by ambulances [16]. P. A. Targe and M. P. Satone developed a real-time algorithm using VANET communication [17]. Poorani K. et al. suggested using image processing techniques to monitor drivers [18]. Kim and Jeong developed an algorithm to detect crashes using crash probability data [19]. Patel K. H. et al. created software to detect accidents using accelerometer sensors [20]. Sonali N. and Maheshwari R. addressed obstacle detection in motorcycles with an intelligent approach. Chris T. and White J. designed a smartphone-based incident detection and notification system [21]. Prabha and Sunitha developed an automatic detection and messaging device for traffic accidents using a GSM modem and GPS [22]. Elie Nasr and Elie Kfoury proposed an IoT method for detecting, reporting, and navigating street accidents, suggesting a rescue system by reporting the location [23]. Vijay Savania and Hardik Agravata created a system for preventing accidents using vehicular alcohol detection sensors [24]. Syedul Amin and Jubayer Jalil proposed an incident detection and reporting device using GPS, GPRS, and GSM technology [25]. Suvarnanandyal et al. suggested a smart parking framework using an IoT module [26]. This review also integrates several recent papers that further emphasize the use of IoT in various applications, including health screening [27], robotic arm control [28], e-health databases [29], highway monitoring [30], Parkinson's prediction [31], and the impact of COVID-19 on education [32]. Additional contributions include low-cost robots for disabled individuals [33], smart farming [34], medical robotics [35], human activity recognition [36] and renewable energy generation [37]. The reviewed literature demonstrates various innovative approaches to vehicle speed control and accident detection using IoT and related technologies. Each study contributes uniquely to enhancing road safety, reducing accident rates, and improving emergency response times. By incorporating these technologies, significant advancements can be achieved in the monitoring and management of traffic, ultimately leading to safer roads and reduced fatalities. The collective insights from these studies highlight the versatility and potential of IoT in transforming various sectors and improving overall quality of life.

B. Research Gap

In reviewing the existing literature, it is evident that while numerous studies have explored the use of IoT and fuzzy logic in traffic management, these approaches often fall short of addressing the complexity and variability of real-world driving conditions. For instance, several works focus on isolated aspects such as monitoring vehicle speed or detecting specific events like accidents or traffic violations through sensor data and GPS/GSM modules. However, these systems tend to operate within predefined parameters, lacking the flexibility to adapt to the dynamic nature of road environments. Furthermore, many studies fail to integrate a comprehensive decision-making framework that considers multiple risk factors simultaneously, such as speed, driver condition, and environmental context. This narrow focus limits their applicability to broader traffic safety scenarios. Additionally, most existing systems do not facilitate real-time interaction between drivers and law enforcement, which is crucial for timely interventions. This research gap highlights the need for a more holistic approach that combines continuous monitoring, adaptive decision-making, and seamless communication to enhance road safety comprehensively. The proposed study seeks to fill this gap by developing an integrated IoT and fuzzy logic-based system that not only monitors vehicle speed in real-time but also incorporates additional risk factors and enables proactive communication between drivers and authorities, thus providing a more robust solution to prevent speeding-related accidents.

C. Novelty of the Proposed System and Comparison with Existing Systems

The proposed system offers several novel features compared to existing systems:

- Integration of fuzzy logic for real-time speed monitoring and decision-making.
- The ability of drivers and police to interact with the system, enhances cooperative safety measures.
- Use of V2X communication for comprehensive traffic management.

Existing systems often focus solely on vehicle speed or accident detection using conventional methods [38], [39], [40], [41], [42], [43]. Our approach enhances these systems by incorporating fuzzy logic and enabling real-time interaction between drivers and law enforcement. Table II shows a Comparison of the Proposed System with Existing Systems.

TABLE II. COMPARISON OF PROPOSED SYSTEM WITH EXISTING SYSTEMS

System	Key Features	Limitations
[38]	Accident detection using speed sensors	Lacks real-time interaction
[39]	GPS and GSM-based monitoring	Limited to vehicle speed
[40]	Traffic management system	No fuzzy logic integration
[41]	Intelligent transport systems	Limited V2X communication
[42]	V2V communication for safety	No driver-police interaction
[43]	Road condition monitoring	Not focused on speed control
Proposed System	Fuzzy logic, V2X, driver-police interaction	Needs further integration

III. METHODOLOGY

The significance of defining a research problem lies in addressing a gap in the literature. The parameters considered in previous work include monitoring gas leaks through sensors, using GPS and GSM modules for communicating vehicle speed, and recording vehicle positions via sensors. However, for accident detection, only the speed monitored by the sensor was considered [38]. We believe this algorithm is more useful for specific intersections than for general traffic accidents. Therefore, the existing work needs to be modified to support road traffic crashes more broadly [39]. In our research, both drivers and police can use this system. They can sign into the system; drivers can monitor and control high speed, while police can detect overspeeding, track current locations, and notify the police control room. Both can receive message notifications from the system.

A. Proposed System Architecture

In this system, the driver signs in and monitors the car's speed. If high speed is detected, a message notification is sent automatically, prompting the driver to control the speed. The driver then signs out of the system. Similarly, police can sign in, detect high speed, receive SMS alerts for high speed, track the current location, and inform the police control room before signing out. The proposed system architecture is shown in Fig. 2.

The flow chart of research work stages and the proposed model for high speed is shown in Fig. 3 and Fig. 4. The following steps outline the flow chart of the research work stages and the proposed system model for high speed.

B. Fuzzy Logic Description

Fuzzy logic is a method of computing based on multivalued logic rather than the standard Boolean "true or false" (1 or 0) logic on which modern computing is based. Fuzzy logic relies on human perception and is used in situations where available information is partially true, making decision-making complex. Fuzzy Logic Controller (FLC) is used here for making decisions on critical events based on sensor data and Vehicle-to-Everything (V2X) communication.

There are some basic units of Fuzzy Inference System (FIS):

- Fuzzification Unit
- Knowledge-Based Rules

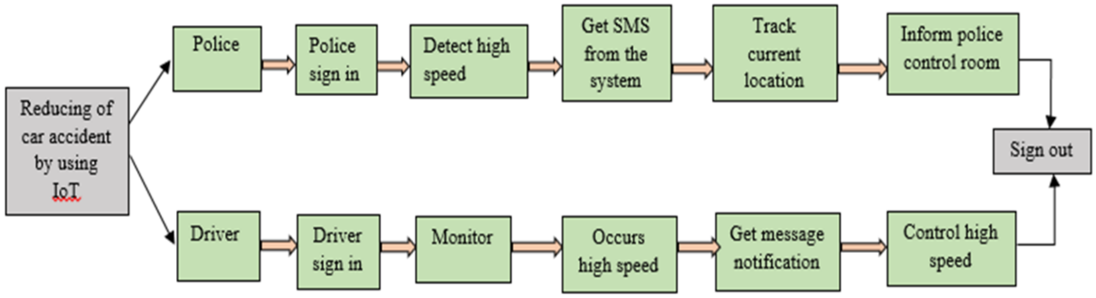

Fig. 2. Proposed system architecture.

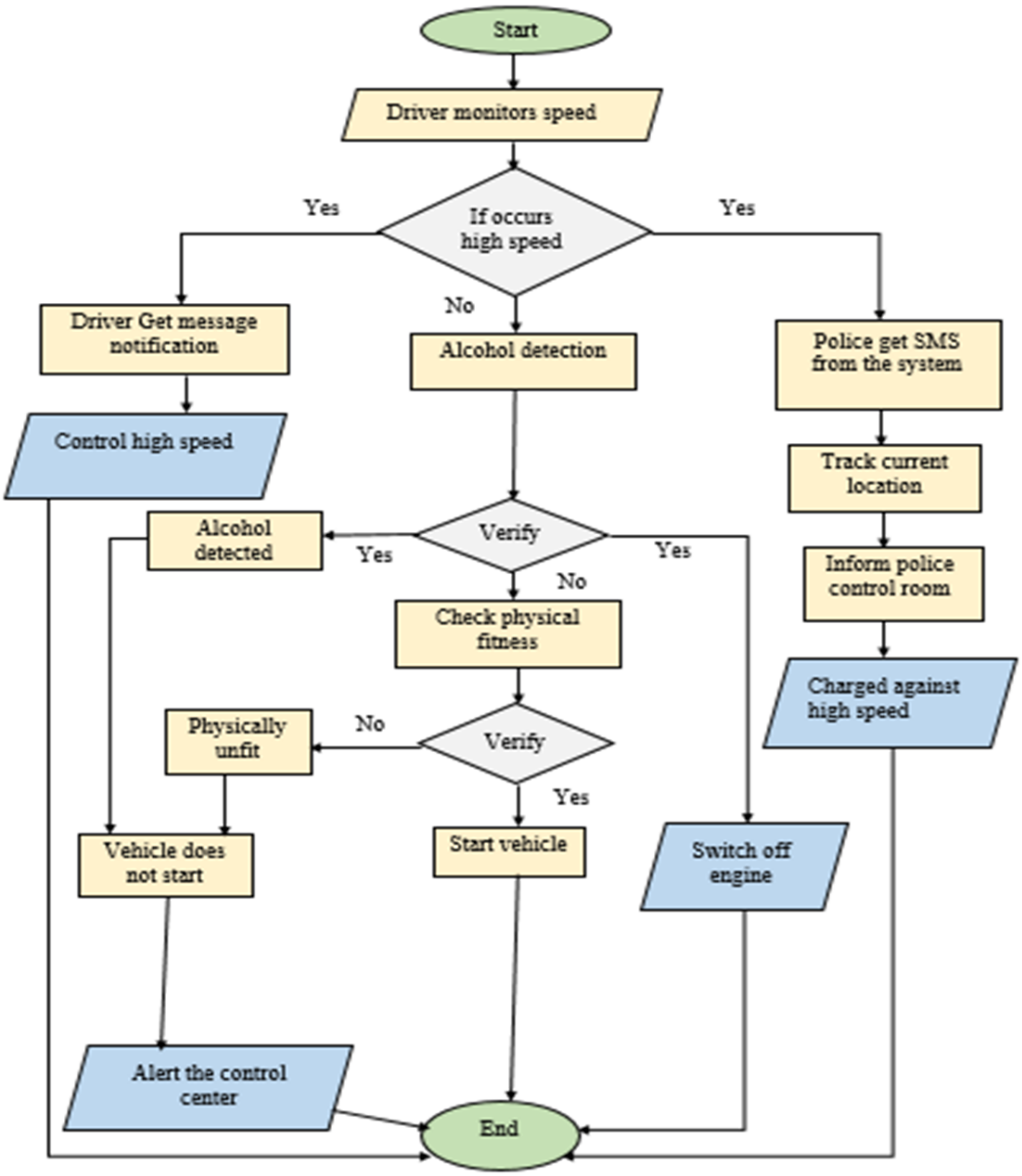

Fig. 3. Flow chart for work stages.

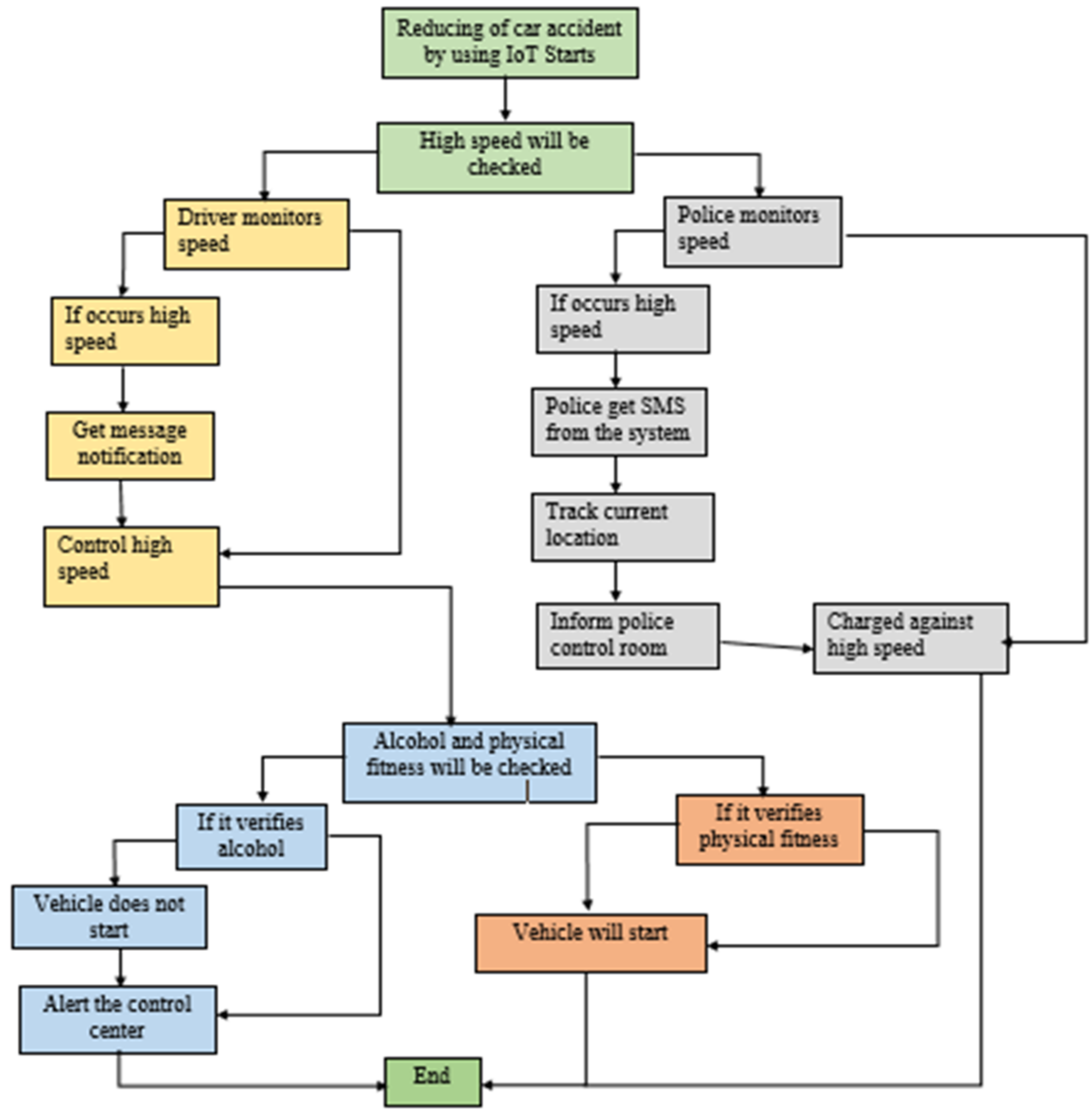

Fig. 4. High speed model.

- Decision or Controller Unit
- Defuzzification Unit

The block diagram of the FIS, shown in Fig. 5, illustrates these four basic units.

C. Mathematical Formulation

Let's consider the speed of the vehicle v, monitored in real-time. The speed threshold for high speed is denoted as v_{th}. If $v > v_{th}$, an alert is triggered. The alert system can be mathematically represented as:

$$A(v) = \begin{cases} 1 & \text{if } v > v_{th} \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

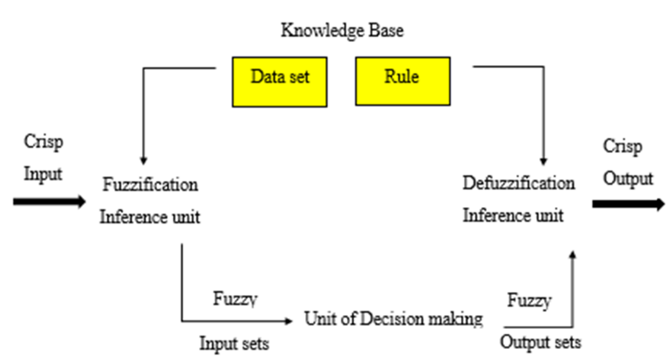

Fig. 5. Block diagram of FIS.

The position of the vehicle, $P(t)$, at time t is tracked using GPS coordinates $(x(t), y(t))$. The rate of change of position, which indicates the speed, is given by:

$$v(t) = \sqrt{\left(\frac{dx}{dt}\right)^2 + \left(\frac{dy}{dt}\right)^2} \tag{2}$$

If $v(t) > v_{th}$, a notification N is sent to both the driver and the police:

$$N = \begin{cases} 1 & \text{if } v(t) > v_{th} \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

Using fuzzy logic, the decision-making process involves fuzzification, applying knowledge-based rules, and defuzzification. The speed $v(t)$ is fuzzified into linguistic variables like "low", "medium", and "high". The rule-based system then decides the action based on these variables. For instance:

- If speed is "high" and location is "urban area", then issue a severe alert.
- If speed is "medium" and location is "highway", then issue a moderate alert.

Defuzzification converts these fuzzy outputs into a crisp value, which determines the exact nature of the alert.

These mathematical formulations and fuzzy logic rules ensure that the system is capable of making nuanced decisions based on real-time data, improving both road safety and the efficiency of emergency responses.

IV. Implementation

This section provides a detailed explanation of the configurations used to complete this research and ensure its functionality. It gives an overview of the software implementation and describes the process of reducing car accidents using MATLAB.

A. Software Implementation

The system is implemented using MATLAB, specifically employing fuzzy logic. A Fuzzy Inference System (FIS) is utilized to achieve the desired functionality. The software components used in the system are:

- MATLAB
- Fuzzy Inference System (FIS)

B. Reducing Car Accidents with High Speed Control in MATLAB

The system is implemented using a Fuzzy Inference System (FIS) in MATLAB. A FIS can be loaded from a .fis file using the `readfis` function. To save a FIS to a file, the `writeFIS` function is used. The `evalfis` function evaluates the FIS for given input values and returns the resulting output values. It evaluates the FIS using predefined evaluation options. The algorithm used in MATLAB is shown in Algorithm 1.

Algorithm 1 Fuzzy Traffic Control

```
f ← readfis('VehicleProtection.fis')
a ← input('Vehicle speed (km/h): ')
g ← evalfis([a, 0, 1], f)
if g < 1 then
    disp('Message to driver is sent')
    disp('Message to police with current location')
    disp('Control room informed')
    disp('Driver punished for high speed')
    b ← input('Is alcohol present (0:no, 1:yes): ')
    c ← input('Is the driver physically fit? (0:no, 1:yes): ')
    g ← evalfis([0, b, c], f)
    if g < 1 then
        disp('Other factors need to be checked')
    else
        disp('Other factors are okay')
    end if
else
    disp('The vehicle is good to go')
end if
```

C. Emergency Speed Control Warning

In this system, the user can observe different speed values. If the speed values are below 65 km/h, the system will indicate that the vehicle is good to go. If the speed is exactly 65 km/h, the system will provide different messages based on various parameters. If the speed exceeds 65 km/h, the system will also provide messages based on the parameters. Table III presents the analysis of speed, alcohol presence, and physical fitness.

TABLE III. Speed, Alcohol, and Physical Fitness Analysis

Speed (km/h)	Alcoholic	Physical Fitness	Message
30	×	×	The vehicle is good to go
50	×	×	The vehicle is good to go
65	0	1	Other factors are okay
65	1	1	Other factors need to be checked
65	0	0	Other factors need to be checked
90	1	0	Other factors need to be checked

V. Results and Discussion

This section discusses the results obtained from our Fuzzy Inference System (FIS) implementation and the performance analysis. The FIS uses fuzzy variables containing sets, where each set has an associated membership function. The membership function defines the form of the sentence and is used to "fuzzify" the values of the variable by associating a degree of membership (DOM) with a value. Sharpe's triangular membership functions are employed in this system. Fig. 6 shows the Mamdani FIS.

A. Obtained Features

The key features obtained from the FIS include:

- Three input variables for speed, alcohol presence, and physical fitness.
- Input and output mapping functions to process and evaluate the data.

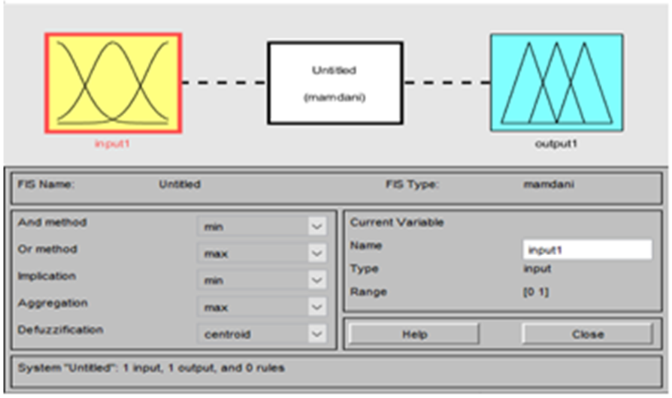

Fig. 6. Mamdani FIS.

- A rule base to determine the actions based on input conditions.
- Surface plots to visualize the relationship between inputs and outputs.

B. Performance Analysis of FIS

1) Three input variables and I/O mapping functions for FIS: The FIS accepts various input variables. Fig. 7 shows the three input variables for this system. The input mapping function receives blocks of data, and the output mapping function returns intermediate results. An input reduction function reads the intermediate results and produces a final result. Thus, mapping calculations are typically split into two related parts, with functions reduced separately. The input and output mapping features of the FIS can be seen in Fig. 8.

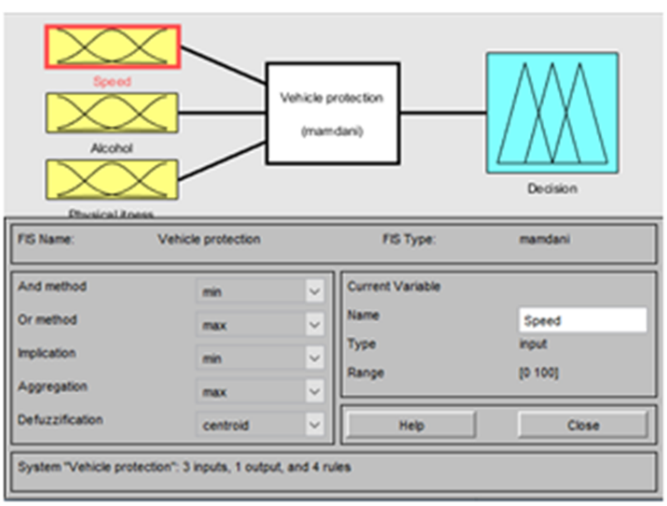

Fig. 7. Three input variables for FIS.

2) Rule base and rule view for FIS: Vehicles often travel at high speeds on roads. For emergency speed control, if speed v is measured in km/h, the rules are:

1) Low: $v < 30$
2) Medium: $20 \leq v \leq 65$
3) High: $v \geq 60$

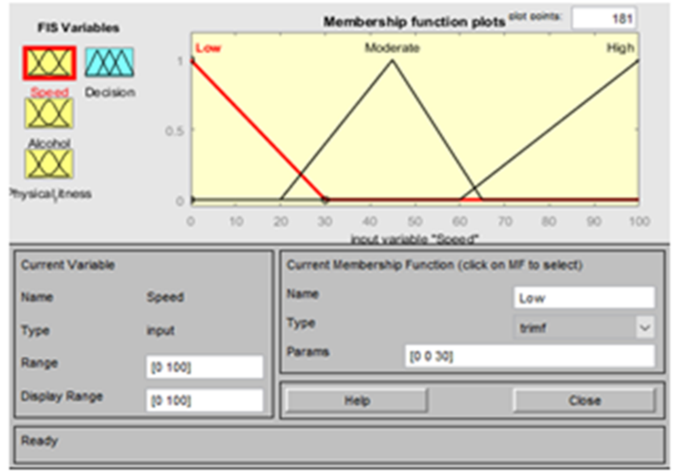

Fig. 8. Input/Output mapping functions for FIS.

Table IV shows the rule base, and Table V shows the decision-making process for emergency speed control to reduce car accidents on highways.

TABLE IV. RULE BASE FOR SPEED CONTROL

SL NO.	Rule Base
1	speed is low: the decision is the vehicle is clear
2	speed is moderate: the decision is the vehicle is clear
3	speed is high: the vehicle stops and necessary steps are taken by the police

TABLE V. DECISION TABLE

Speed	Decision
Low	Vehicle is clear
Moderate	Vehicle is clear
High	Vehicle stops and necessary steps are taken by the police

The rule view for the determination of decisions according to input is shown in Fig. 9.

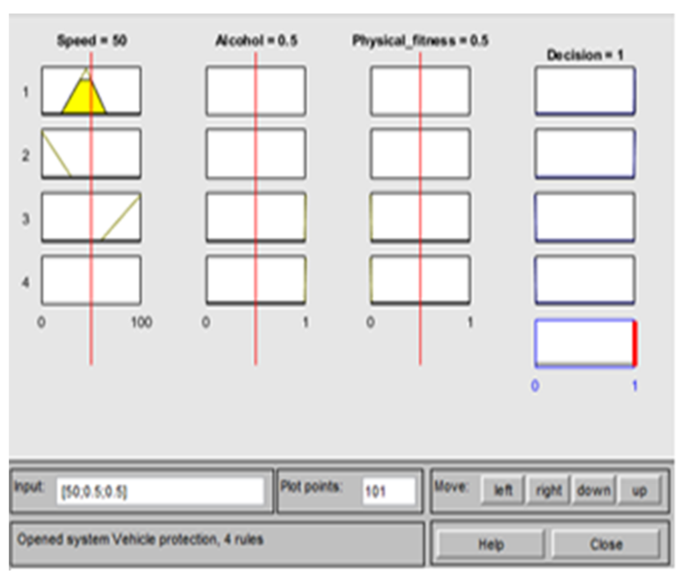

Fig. 9. Rule view for FIS.

3) Surface for FIS: The surface plot from the FIS shows the relationship between input and output variables. Fig. 10 depicts the surface according to the input.

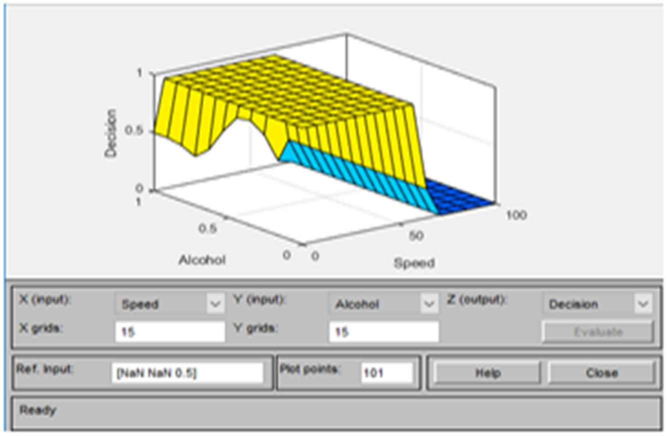

Fig. 10. Surface for FIS.

C. Limitations

While the FIS model provides a robust framework for speed control and accident reduction, it has some limitations:

- The system relies heavily on accurate sensor data, which may not always be available.
- The model's effectiveness is constrained by the predefined rules and membership functions, which might not cover all real-world scenarios.
- Integration with other traffic management systems is not addressed in this implementation.

D. Future Works

Future improvements and extensions to this research could include integrating the system with other traffic management systems for a more comprehensive solution, expanding the FIS rules to cover a broader range of driving conditions and scenarios, incorporating machine learning techniques to adaptively modify the FIS rules based on real-time data, and enhancing the sensor network to improve data accuracy and reliability.

VI. Conclusion

This study introduces an innovative approach to enhance road safety through the integration of IoT and fuzzy logic technologies for real-time vehicle speed monitoring and accident reduction. Our system leverages IoT sensors to continuously monitor vehicle speeds and employs fuzzy logic for decision-making based on variables like speed, alcohol presence, and driver fitness. This approach enables timely interventions by notifying both drivers and law enforcement agencies of potential speeding violations, thereby mitigating the risk of accidents. The system's capability to facilitate interaction between drivers and police, coupled with Vehicle-to-Everything (V2X) communication, enhances cooperative safety measures and improves traffic management. Although our Fuzzy Inference System (FIS) demonstrated effective speed control capabilities in our analysis, its performance is contingent on accurate sensor data and predefined rules, suggesting avenues for future enhancements. By integrating machine learning for adaptive rule adjustments and refining sensor networks for enhanced reliability, future research aims to further optimize our system's efficacy in ensuring safer and more efficient transportation systems globally.

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