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IoE-powered Smartphone Feedback for Real-time Driver Improvement

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Abstract

This research analyzes risky driving that contributes to accidents and environmental damage from existing data. Existing driver monitoring systems, which analyze driving patterns through diagnostic data, fail to provide specific real-time feedback for critical events. This study proposes an innovative framework built on the Internet of Everything (IoE) that leverages in-vehicle sensors and smartphones to deliver real-time contextual driving feedback. The system measures hard accelerations and detects unsafe turns by analyzing time-series data from accelerometers and gyroscopes. Machine learning algorithms enable instant alerts during these critical events, prompting drivers to modify their behavior. The developed graphical user interface enables drivers to visually represent and comprehend many sensor data related to driving incidents, facilitating self-evaluation and corrective actions. Nevertheless, for the smartphone-based IoE solution to effectively enhance driving performance by providing real-time feedback, it is imperative to tackle obstacles such as energy consumption, data dependability, metrics formulation, and user approval. The system prioritizes user privacy - identity abstraction techniques reduce concerns about driver monitoring. Additionally, a user-friendly graphical interface presents analytical data to encourage self-improvement in driving habits. Field tests will evaluate the system's effectiveness, with plans for integration with emerging vehicle-to-infrastructure (V2X) connectivity to enhance functionality. The analysis results of this ethical and accessible IoE system will have a large-scale positive impact on driving habits, safer road use and a more conducive environment.

1. Introduction

Risky driving behaviour such as speeding, rapid acceleration, rapid braking and aggressive manoeuvres increase traffic accidents and fatalities yearly [1]. Beyond safety impacts, such driving practices also negatively affect fuel efficiency and environmental impact due to accelerated wear and emission levels [2]. However, research shows that modifying driving habits can reduce associated risks and fuel consumption [2].

Prior systems have aimed to improve driving behaviour through data analytics but lacked real-time feedback. For example, diagnostics port (OBD-II) and insurance tracking devices enable only post-trip driving scoring with limited visibility during the actual drive [3][4]. In addition, such systems also face challenges related to operational costs, limited access to driver data and difficulty correlating scores with precise driving events [5][6].

With the proliferation of smartphone devices with built-in sensors, recent research has proposed leveraging smartphone sensor data to classify and provide real-time feedback on driving behaviour [7]-[9]. Other than that, several challenges remain unaddressed that have impeded the feasible implementation of real-time driving behaviour improvement systems thus far, including issues of privacy intrusion through continuous driver monitoring [10][11], lack of engaging interfaces and effective incentive mechanisms to sustain driver involvement over time [12]. Existing driver monitoring systems fail to provide specific real-time feedback for critical events, lacking in engagement and effective incentive mechanisms to sustain driver involvement. This paper addresses these gaps by proposing an ethical, accessible IoE framework that leverages in-vehicle sensors and smartphones to deliver real-time contextual driving feedback while tackling challenges like energy consumption, data dependability, metrics formulation, and user approval.

Therefore, this study aims to delineate an ethical, accessible framework using Internet of Everything (IoE) connectivity and intelligence for impactful driving behaviour improvement. The system aims to provide contextual real-time feedback to drivers by sensing salient vehicle manoeuvres utilizing existing in situ smartphone sensor data; detecting critical risky events with precision employing machine learning techniques; visualizing sensor data and metrics through an intuitive graphical user interface (GUI); incentivizing self-improvement implementing gaming dynamics and motivational scaffolds; and respecting user privacy through secure identity handles decoupled from actual personal identifiers.

2. System Model

In this study, the dataset obtained from IEEE Dataport [13] and Kaggle [14]. Table 1 lists the parameters used in the study on driver behavior analysis. It compares the data collected from three different sensors: accelerometer, gyroscope, and pressure sensor.

- Timestamp is recorded in milliseconds.
- Accelerometer Data records data for all three axes (X, Y, and Z)
- Gyroscope Data records data for X and Y axes only.
- Pressure Data is recorded in millibars.

It is important to note that the image you sent me does not mention a study by Wawage or that the dataset was obtained from IEEE Dataport.

Table 1 *Parameter setting*

	Accelerometer Data	Gyroscope Data	Pressure Data
Timestamp	√	√	√
Milliseconds	√	√	√
X	√	√	
Y	√	√	
Z	√	√	
Millibars			√

2.1 The IoE Framework

The IoE framework for the driving behavior analysis system can be related to the four pillars of IoE: People, Process, Data and Things. The driver's behavior and actions are central to this data. The accelerometer, gyroscope and other sensor data reflect how the driver operates the vehicle. This aligns perfectly with the people pillar of the Internet of Things (IoT) framework, where human users are a core component of the system. The relevant dataset parameters are acceleration (X,Y,Z), rotation (X,Y,Z) and orientation from Accelerometer and Gyroscope data. The IoE system can leverage this driver-centric data to create a personalized mobile interface and provide real-time feedback for improved driving habits.

The driving process has several events like acceleration, braking, turning etc. IoT devices like smartphones and in-vehicle sensors can capture granular data to model these processes, detect patterns and evaluate driving behavior KPIs. This aligns with the process pillar of the IoE framework, which focuses on optimizing information flow and interactions between the various components of the system. The sensor data can be fed into algorithms and analytics processes to quantify driving behavior. The process pillar of the IoE system includes data ingestion (loading and parsing CSV sensor data); Storing time series data from CSVs; Sensor data processing (filtering, and synchronizing data from different sensors); Analytics to detect events like acceleration, turns etc. and model driver behavior; and provide real-time feedback for harsh braking, over-speeding etc. Integrating such data with business processes like fleet management and delivery logistics can optimize operations.

The multi-sensor time series measurements in this dataset enable quantitative analysis of driving behavior events. This aligns with the data pillar of the IoE framework, which emphasizes the importance of collecting, storing, and managing the vast amount of data generated by connected devices. The relevant dataset parameters are time series sensor measurements: acceleration, rotation rate, pressure, and Timestamp, X, Y, Z axis values from all three sensors data (Accelerometer, Gyroscope and Pressure). Additional contextual data like weather, traffic, vehicle diagnostics could enrich insights. IoE analytics can fuse and analyze such heterogeneous data streams.

Smartphones and in-vehicle sensors that collect various telemetry data are at the edge of this IoE system. This aligns with the things pillar of the IoE framework, which focuses on the physical devices and objects that are interconnected and generate data. The smartphone maps to a thing, which is the vehicle, through the sensors inside: accelerometer, gyroscope, pressure sensors. Beyond passive data collection, capabilities like Advanced Driver-Assistance Systems (ADAS), driver monitoring, real-time alerts make these devices active. Emerging V2X connectivity between vehicles and infrastructure further expands the range of "things" that can contribute data and functionalities within the IoE system.

2.2 GUI Development

This work presents the development of a user-friendly GUI program designed to bridge the gap between raw sensor data and public understanding. By translating complex datasets into visually appealing and interactive formats, the GUI empowers users to gain valuable insights into the processes that generate the data. This newfound knowledge can then be leveraged to optimize and improve business practices across various domains.

In the context of driver behavior analysis, we developed a dedicated GUI program to present sensor data to the public. The program leverages clear and concise visualizations, such as line charts and heat maps, to effectively communicate trends and patterns within the sensor readings. This empowers drivers to gain a deeper understanding of their driving habits, allowing them to identify areas for improvement and ultimately promote safer and more efficient driving practices.

It's important to acknowledge the limitations of the dataset used for this project. While the program is designed to visualize pressure sensor data alongside other sensor readings, the original dataset contained only zero values for pressure readings. To showcase the full functionality of the GUI and its ability to handle pressure data, the program utilizes dummy values for demonstration purposes.

For a more comprehensive understanding of the GUI's functionalities, screenshots and source code are provided in the following Figures. This allows for further exploration and potential customization of the program for various data visualization needs. This approach of utilizing a user-friendly GUI for data presentation fosters public engagement with complex datasets and empowers individuals to translate data into actionable insights, ultimately paving the way for improved decision-making across various sectors.

3. Results and Discussion

The graphical user interface (GUI) developed allows the visualization of the multi-sensor time series data related to driving events. As shown in the screenshot figures, the acceleration, rotational velocity and pressure data can be plotted as trends over time. This can help drivers self-analyze their driving performance and take corrective actions.

The challenges associated with implementing the proposed smartphone-based IoE solution for real-time driving feedback include energy overhead, where continuous background sensing and processing sensor data strain the smartphone battery, making feasibility dependent on optimized and adaptive sensing algorithms. Data reliability is another issue, as sensor data quality can vary across phone models and due to positioning, which necessitates calibration mechanisms and data augmentation to address this variability. Metrics design is crucial, as key driving Key Performance Indicators (KPIs) need to be defined to quantify aggressive acceleration, unsafe turning, and other behaviors based on signals. Finally, user acceptance is a significant challenge, as drivers may resist behavioral changes unless motivated through effective engagement strategies and reassured about their privacy.

Compared to prior work discussed in Section 1 that also analyse naturalistic driving data [3]-[8], the proposed IoE approach aims to provide more instantaneous feedback. By detecting unsafe events from smartphone sensors, it addresses limitations in other systems with only post-trip driving scores [5]. The user-centric interface and motivational design also contrast insurance-based solutions [3] that drivers can perceive as intrusive [11]. Overall, the proposed smartphone IoE system offers promise for accessible, ethical and impactful driving performance improvement.

The GUI developed demonstrates initial feasibility, though optimisations in sensing, analytics and interfaces are necessary for large-scale adoption. Testing efficacy via field studies would be the next step. Integration with emerging V2X infrastructure could also enhance such IoE systems. Fig. 1 provides specific data points that contribute to the overall trends observed in the first figure. For example, the accelerations recorded at 10:45:08 show minor fluctuations, but the spikes or disturbances would be more noticeable in a broader timeline. On the other hand, in Fig. 2 X-axis values from this table can be related to the color intensities. For example, the X-axis acceleration values range from 0.0069 to 0.565 and beyond, which correspond to different color intensities in the heatmap, showing how the X-axis acceleration changes over time. For the acceleration data, the accelerations along the X, Y, and Z axes change rapidly within a short time frame (within milliseconds). The Z-axis acceleration remains relatively high, indicating a consistent force or movement along that axis. The Y-axis shows a significant negative acceleration, indicating movement in the opposite direction.

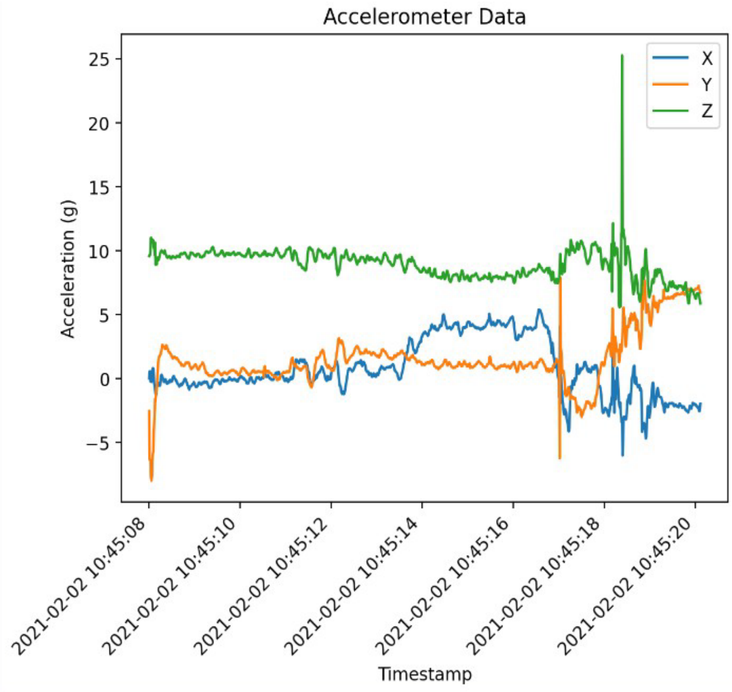

Fig. 1 *Accelerometer data*

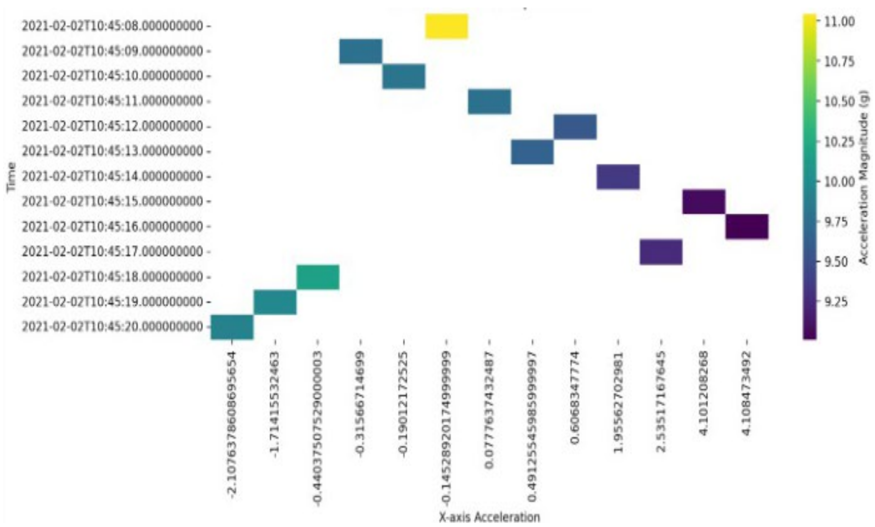

Fig. 2 *Acceleration heatmap timeline*

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For Figure 3 and Figure 4, the accelerometer data along the x, y, and z axes measure lateral, longitudinal, and vertical acceleration, respectively, enabling the detection of harsh braking, rapid acceleration, sharp turns, and vertical movements. The gyroscope data along the same axes capture the vehicle's pitch, roll, and yaw, providing insights into unsafe turns, vehicle tilting, and potential rollovers, thereby enhancing the analysis of driving dynamics and safety.

	Timestamp	Milliseconds	X	Y	Z
0	2021-02-02 10:45:08	0	0.0069	-2.5406	9.5755
1	2021-02-02 10:45:08	22	0.565	-6.3281	9.6619
2	2021-02-02 10:45:08	22	0.565	-6.3281	9.6619
3	2021-02-02 10:45:08	30	-0.2231	-6.5052	10.3421
4	2021-02-02 10:45:08	40	0.4259	-7.7533	11.0154

Fig. 3 *Tabulated accelerometer data*

	Timestamp	Milliseconds	X	Y	Z
0	2021-02-02 10:45:08	3	-0.4554	0.098	-2.1723
1	2021-02-02 10:45:08	22	-0.4437	-0.264	-1.6429
2	2021-02-02 10:45:08	22	-0.4437	-0.264	-1.6429
3	2021-02-02 10:45:08	30	-0.3265	-0.247	-1.4097
4	2021-02-02 10:45:08	40	0.0675	-0.1288	-0.9209

Fig. 4 *Tabulated gyroscope data*

The incorporation of gyroscope data with velocity and positional data in the x, y, and z axes is illustrated in Fig. 4, Fig. 5 and Fig. 6 greatly improves vehicle dynamics and stability control. In Figure 6, the heat map's color intensity helped us quickly identify periods of high rotational activity, which often correlate with unsafe driving maneuvers like sharp turns or abrupt lane changes. Gyroscope data tracks the vehicle's pitch, roll, and yaw, offering vital insights into its orientation. Velocity data provides information about the vehicle's speed and direction of motion, while x, y, z data monitors its exact position in three-dimensional space. This extensive data integration enables stability control systems to make accurate modifications to braking and steering inputs, thereby averting sliding or rollover incidents by preserving the vehicle's ideal stability. Figure 7 shows the pressure data collected from sensors measuring changes in air or brake pressure, providing additional insights into driving behavior. This data helps identify events such as hard braking, sudden stops, or rapid deceleration, offering a more comprehensive understanding of a driver's actions and the vehicle's response in various situations. The data shows fluctuations in pressure over a short period, which can be linked to specific driving events. In situations involving hard braking, a sudden and significant drop in pressure could indicate a hard brake, typically occurring when the driver makes an abrupt stop to avoid a collision or in response to an unexpected event. Rapid declines to a low-pressure point may correspond to sudden stops, where the vehicle comes to a quick halt. Conversely, rapid deceleration is reflected in a gradual or step-like decrease in pressure, suggesting the driver is slowing down quickly but not abruptly, possibly due to changes in speed limits, upcoming turns, or traffic conditions. During normal driving conditions, minor fluctuations around a stable pressure range likely reflect a consistent driving speed with small adjustments as needed.

When analyzed over time, this pressure data offers a comprehensive understanding of the driver's behavior and the vehicle's response. Consistent patterns of hard braking, for example, could indicate aggressive driving, whereas smooth pressure transitions may point to a more cautious and controlled driving style. By combining this data with other sensor inputs such as acceleration, GPS location, and vehicle speed, a detailed profile of driving habits can be created, identifying areas for improvement and enhancing safety through informed feedback.

In addition, the combination of gyroscope, velocity, and location data can significantly aid in traction control. Gyroscope data detects changes in the vehicle's orientation, while velocity data indicates acceleration and deceleration patterns. The x, y, z location data provides real-time positioning. By integrating these various data sources, more precise adjustments can be made to the power distribution to the wheels, leading to improved grip and control. These integrated systems enhance the understanding of vehicle dynamics and location, contributing to a safer, more efficient, and responsive driving experience in V2X (vehicle-to-everything) situations.

Developing a real-time dashboard that displays accelerometer, gyroscope, pressure, and velocity data could significantly improve driver awareness and reactivity. Such a dashboard could showcase a range of driving parameters, including acceleration, deceleration, and lateral movements, allowing drivers to monitor their behavior in real-time. With instant feedback, drivers can quickly adjust their driving techniques, reducing instances of abrupt braking, forceful acceleration, and sharp turns, ultimately fostering a safer and more efficient driving experience.

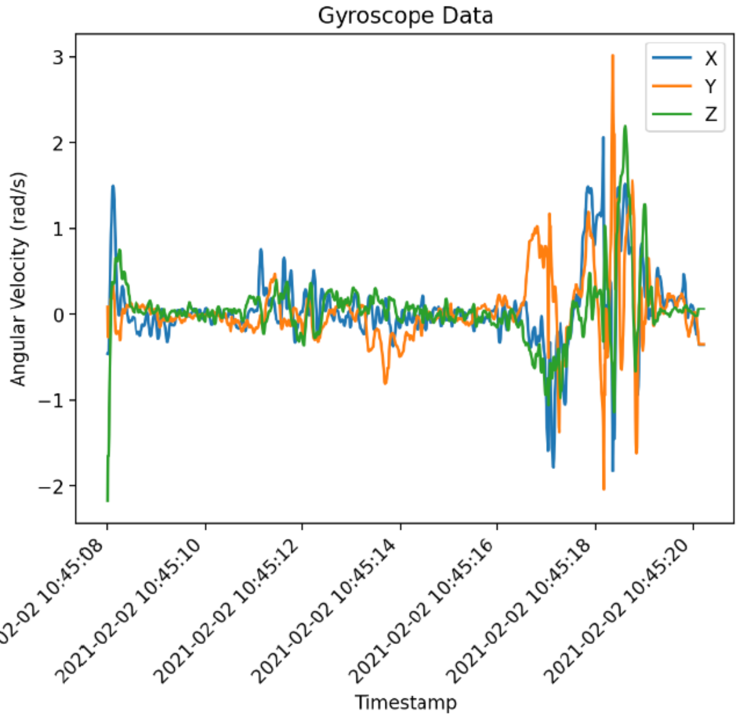

Fig. 5 *Gyroscope data*

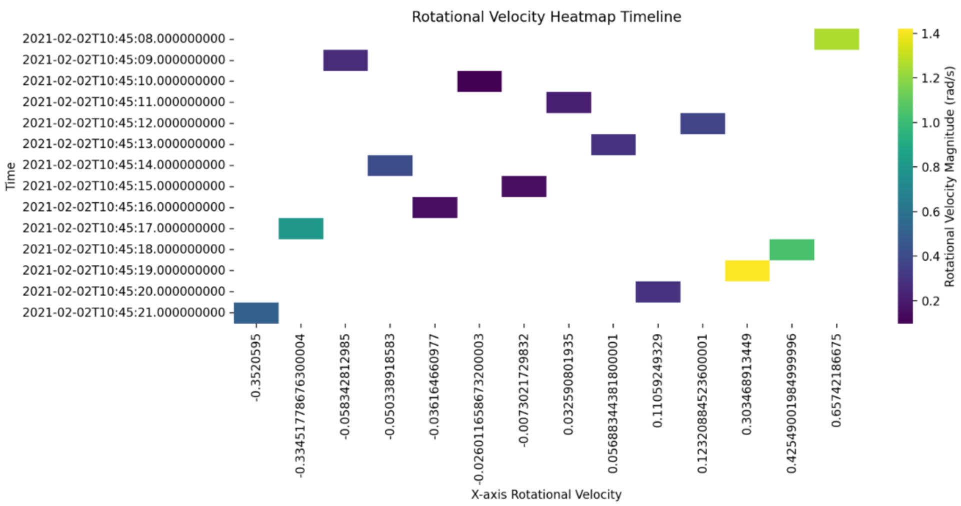

Fig. 6 *Rotational velocity heatmap*

Aside from real-time monitoring, conducting post-trip analysis can serve as a potent technique for enhancing long-term driving performance. Following each journey, drivers can obtain comprehensive reports and visual representations of their driving performance, like the illustrations displayed in the provided examples. These reports can emphasize important measurements such as mean acceleration, frequency of abrupt halts, and occurrences of quick turns. Through the analysis of this data, drivers can pinpoint specific areas for improvement, such as optimizing acceleration and braking techniques and enhancing their ability to anticipate road conditions. This process of reflection fosters ongoing enhancement and cultivates a culture that prioritizes driving safety.

Alerts and notifications function as quick stimuli to promote safer driving behaviors. Enabling alerts for instances of high acceleration, such as sudden braking or quick acceleration, can promptly inform drivers to modify their actions. These alerts can be transmitted through many channels, such as dashboard warnings, mobile notifications, or audio signals.

This prompt feedback assists drivers in developing greater awareness of their driving behaviors and motivates them to adopt a more careful driving approach. Over some time, this can result in the formation of more secure driving behaviors, hence decreasing the likelihood of accidents and enhancing road safety in general.

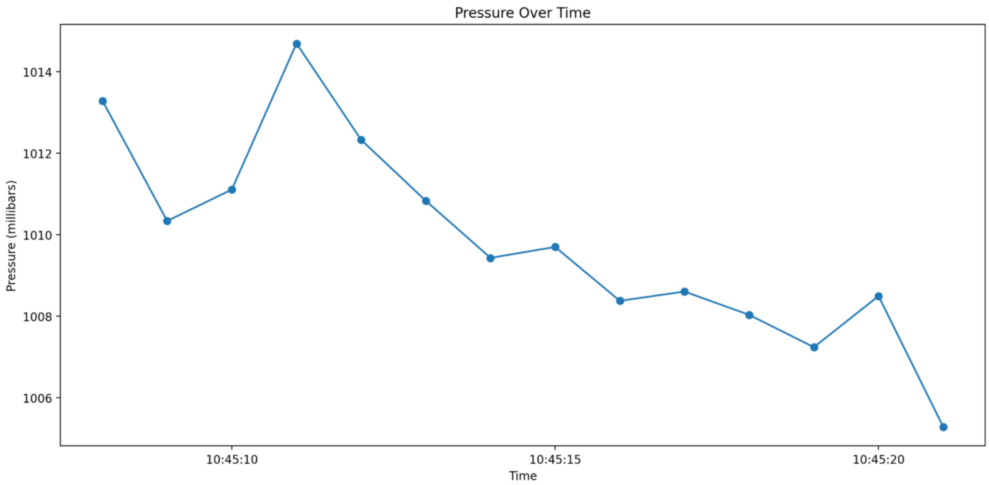

Fig. 7 *Pressure data*

4. Conclusion

Risky driving practices that are aggressive, rash, and distracted are a major and growing threat to road safety as well as environmental impact from vehicular emissions. However, research shows that providing instantaneous feedback to drivers can promote self-correction and analysis of harmful habits. This paper proposed an IoE framework that utilizes in-situ smartphone sensory capabilities for context-aware driving feedback. The system detects critical events like harsh braking based on accelerometer data; processes this and related vehicular time-series data to extract safety and efficiency metrics leveraging machine learning; conveys intuitive visualization and alerts through a smartphone interface; incentivizes improvement over time using gaming elements and motivation scaffolds, while respecting user privacy concerns through anonymous identifiers. A graphical user interface implementation demonstrated the initial feasibility of the approach. Future work should conduct rigorously controlled field trials across diverse geographical areas to evaluate real-world efficacy. The solution can be enhanced by incorporating emerging V2X infrastructure to augment in-vehicle sensor capabilities. Overall, the smartphone IoE solution proposed in this paper offers a scalable platform to instigate positive driving behavioral change through actionable, ethical intelligence. Widespread adoption can significantly improve road safety outcomes and environmental impact given the high market penetration of smart devices. However, several research challenges still need investigation regarding optimized algorithms, robust predictive analytics, sustained user engagement, and public policy implications to fully realize this preventive vision globally. Future work for this research involves running carefully controlled field trials in various regions to see how well the IoE framework performs in real-life situations. We also aim to enhance the system by integrating new V2X infrastructure, refining the algorithms, and developing more reliable predictive analytics to boost road safety and lower environmental impact.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Lim Thean Yew, Hazilah Mad Kaidi;* ***data collection:*** *Lim Thean Yew;* ***analysis and interpretation of results:*** *Lim Thean Yew, Siti Nur Aisyah Mohd Robi, Fadhilah Abdul Razak;* ***draft manuscript preparation:*** *Hazilah Mad Kaidi, Siti Nur Aisyah Mohd Robi. All authors reviewed the results and approved the final version of the manuscript.*

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