SHIHAB JOURNAL OF HUMANITIES
Volume (2), Issue (1) (March, 2026)
ISSN: 3136-2958

مجلة الشهاب للعلوم الإنسانية
المجلد (2) العدد (1) مارس 2026
ردمد: 3136-2958

Design of a Smart Vehicle Safety System Based on Real-Time Driver Blood Glucose Monitoring: A Software-Based Framework forRoad Safety in Libya

Morad Hussain Kaib [1], Ehsan Altayef [2], Abeed ALtaqazi [3], Rabee ahaldali [4]
[4-1] Al-Zahra Higher Institute of Science and Technology, Al-Zahra City, Libya
**Corresponding Author's Email :abeadaba@gmail.com*

Abstract

Diabetes mellitus is an important public health concern, and acute disturbances in blood glucose, particularly hypoglycemia, may temporarily affect cognitive and psychomotor functions required for safe driving. In Libya, the prevalence of diabetes and the burden of road traffic injuries highlight the importance of exploring additional approaches to driversafety.

This paper proposes a software-based glucose-aware vehicle safety framework that uses real-time glucose data to identify potentially unsafe driving conditions. The proposed system analyzes the current glucose level, its temporal trend, and the persistence of abnormal conditions to classify driving risk into four levels: Normal, Caution, High Risk, and Critical. Each risk level is associated with a graduated software response, ranging from driver warnings to a simulated gradual speed-reduction and safe-stop strategy.

The proposed framework is designed for simulation-based evaluation rather than immediate physical vehicle control. Different glucose scenarios, including stable, decreasing, rapidly decreasing, low-glucose, high-glucose, and recovery conditions, are used to evaluate classification correctness, response time, false-alarm behavior, anddetection consistency. The software-only approach provides a controlled and low-cost environment for testing the proposed decision logic before future integration with real-time continuous glucose monitoring devices and vehicle-control platforms.

Keywords—diabetes, blood glucose monitoring, continuous glucose monitoring, driver safety, risk classification, vehicle safety, software simulation, Libya.

INTRODUCTION

Road safety is influenced not only by road and vehicle conditions but also by the physiological and cognitive state of the driver. Driver-health monitoring has therefore become an important research area within intelligent transportation systems and advanced driver-assistance systems [3], [4].

Diabetes presents a particular safety consideration because acute changes in blood glucose, especially hypoglycemia, may affect attention, information processing, reaction time, and psychomotor performance. Importantly, diabetes itself should not be considered an indication that an individual is unsafe to drive; rather, the concern is the occurrence of temporary glucose-related conditions that may impairdriving ability [5].

Continuous glucose monitoring (CGM) provides an opportunity to monitor glucose continuously during daily activities, including driving. Trawley*et al.* demonstrated that glucose levels can change substantially during relatively short driving journeys, supporting the value of continuous monitoring during travel [6]. More recently, Maeda *al.* reported that CGM with low-glucose alerts reduced the incidence of low-glucose events while driving among insulin-treated drivers [7].

In-vehicle glucose-related warning systems have also been investigated. Bérubé demonstrated the feasibility of multimodal in-vehicle hypoglycemia warnings using visual and voice-based cues [8]. These studies demonstrate the potential of glucose monitoring and driver alerts, but they primarily address monitoring and warning rather than a complete software framework that classifies risk and generates graduated safety responses.

This study therefore proposes a software-based glucose-aware vehicle safety framework. The framework combines current glucose information with glucose trend and persistence to classify potential driving risk and generate an appropriate graduated software response. The proposed system is evaluated through controlled simulation and is intended as a foundation forfuture real-time and physical implementation

LITERATURE REVIEW

Research related to glucose-aware driving safety can be grouped into three main areas. The first concerns the relationship between diabetes, hypoglycemia, and driving performance. The American Diabetes Association has emphasized that acute hypoglycemia may affect cognitive and psychomotor functions relevant to driving safety [5].

The second area concerns continuous glucose monitoring during driving. Trawley*et al.* showed that glucose levels can change considerably during relatively short journeys and suggested that CGM-based information could support safer driving [6]. Maeda *al.* subsequently demonstrated that low-glucose CGM alerts can reduce the occurrence of low-glucose events while driving [7].

The third area concerns physiological driver monitoring and in-vehicle warning systems. Bérubé*et al.* demonstrated the feasibility of multimodal in-vehicle hypoglycemia warnings [8], while broader reviews have examined wearable and non-wearable technologies for monitoring driver state and health [3], [4]. Other studies have demonstrated low-cost physiological monitoring using embedded and wearable systems [9], [10], while smartwatch-based monitoring has also been investigated as a practical approach fordrivermonitoring [11].

Although these studies demonstrate the feasibility of glucose monitoring, health-related warnings, and physiological driver monitoring, they generally address these functions separately. Limited attention has been given to integrating real-time glucose information, temporal glucose trends, risk classification, and graduated safety responses within a single software framework. This gap motivates the proposed system.

RESEARCH GAP AND PROPOSED CONTRIBUTIONS

Existing research demonstrates the value of CGM, glucose-related driver warnings, and physiological driver monitoring. However, these approaches largely focus on individual aspects of the problem. In particular, limited work has addressed the integration of current glucose level, glucose trend, persistence, and driving-related risk within a single decision-making framework.

The proposed study addresses this gap through a software-based glucose-aware vehicle safety framework with the following contributions:

1. **Glucose-aware software architecture:** Integration of glucose data processing, risk classification, and safety decision making within a unified framework.
2. **Temporal risk assessment:** Consideration of both current glucose level and its temporal trend ratherthan relying only on a single measurement.
3. **Multi-level risk classification:** Classification of the detected condition into four software-defined risk levels.
4. **Graduated safety response:** Progressive responses ranging from driver warnings to a simulated speed-reduction and safe-stop strategy.
5. **Simulation-based validation:** Evaluation of the proposed decision logic using predefined glucose scenarios before future physical implementation.

PROPOSED SOFTWARE SYSTEM ARCHITECTURE

The proposed system is a software-based glucose-aware vehicle safety framework. It receives simulated or externally provided time-stamped glucose data and processes these data through a sequence of software modules.

The architecture consists of five principal modules:

A. Glucose Data Input

This module receives time-stamped glucose measurements representing the driver's glucose condition. For the current study, the input is simulated or obtained from previously available data ratherthan directly connected to a physical CGM device.

B. Data Processing

The data-processing module validates incoming measurements and identifies missing orinvalid values before furtheranalysis.

C. Glucose Trend Analysis

The system evaluates the temporal behavior of glucose. The rate of glucose change is calculated as:

whereis the current glucose measurement, is the previous measurement, and is the sampling interval.

The resulting trend is classified as stable, increasing, decreasing, orrapidly decreasing.

D. Risk Classification

The classification module combines the current glucose condition, glucose trend, and persistence of abnormal measurements to assign one of fourrisk levels:

- **Level 0 – Normal**
- **Level 1 – Caution**
- **Level 2 – High Risk**
- **Level 3 – Critical**

The detailed classification rules are presented in Section V.

E. Safety Decision

The safety decision module converts the risk level into a predefined software response. Normal conditions produce no intervention, while increasing risk levels generate progressively stronger warnings and, under critical persistent conditions, a simulated gradual speed-reduction response.

The complete software flows:

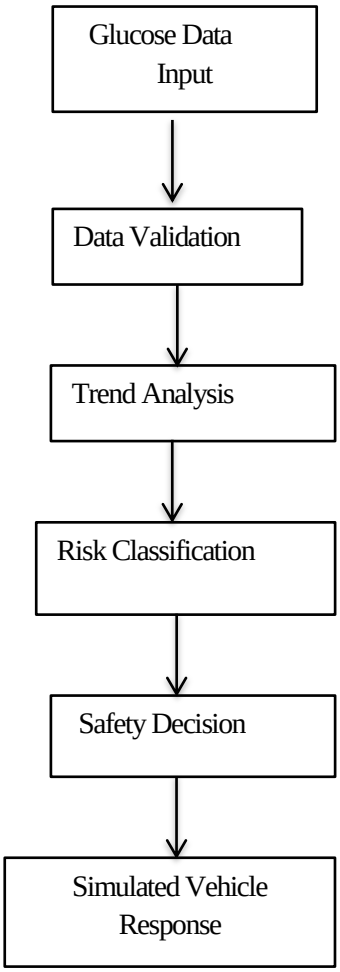


Fig. 1. Proposed software architecture of the glucose-aware vehicle safety system.

GLUCOSE-RISK CLASSIFICATION MODEL

The glucose-risk classification model converts incoming glucose measurements into a software-defined driving-risk level. The model considers the current glucose value, its temporal trend, and the persistence of abnormal conditions.

The current glucose measurement is first compared with predefined glucose ranges.
The rate of change is then evaluated using (1) to determine whether glucose is stable orchanging.

The proposed system uses foursoftware-defined risk levels:

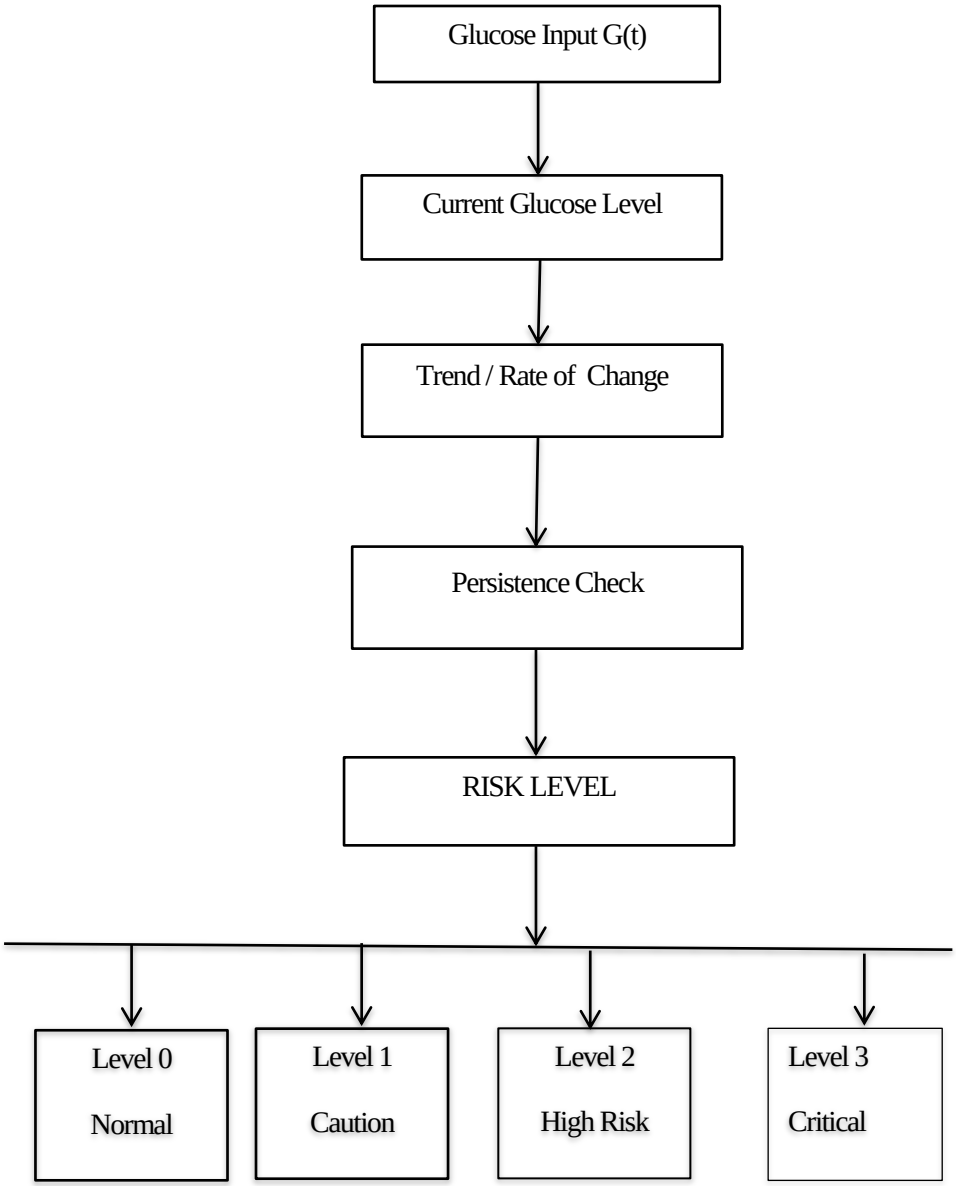
TABLE I

GLUCOSE-RISK CLASSIFICATION

Risk Level	**General Condition**	**Software Response**
Level 1 – Caution	Acceptable glucose condition and stable trend	Normal driving status
Level 2 – High Risk	Significant or persistent abnormal condition	Intensified warning and safe-stop recommendation
Level 3 – Critical	Critical or rapidly deteriorating condition	Highest warning level and simulated gradual speed reduction

To reduce false alarms caused by isolated measurements, escalation to a higher risk level requires the abnormal condition to persist for a predefined number of measurements or time interval. The system can similarly reduce the risk level after sufficient recovery.

The classification is intended as a**driving-safety mechanism rather than a medical diagnostic tool**.



VEHICLE SAFETY DECISION MECHANISM

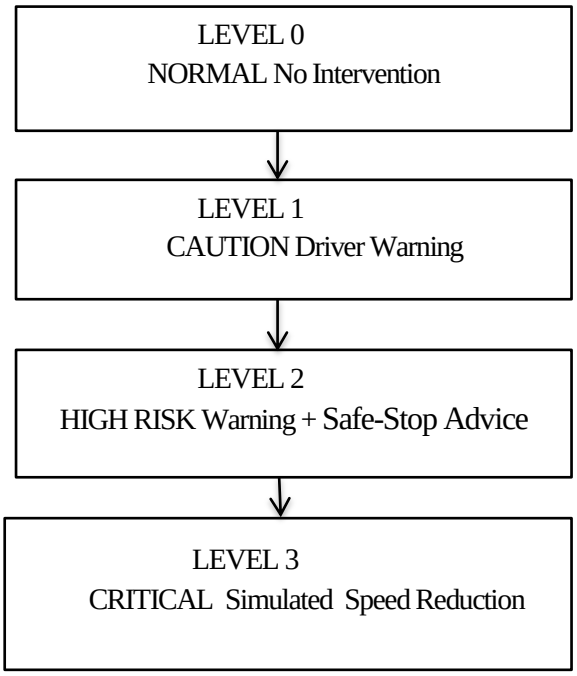
The Vehicle Safety Decision Mechanism converts the risk level into an appropriate software response.

TABLE II
RISK LEVEL AND
SAFETY RESPONSE

Risk	Safety State	Software Response
Level 0	Normal	No intervention
Level 1	Caution	Visual and/or audible warning
Level 2	High Risk	Repeated warning and safe-stop recommendation
Level 3	Critical	Highest-priority warning and simulated gradual speed

The proposed response is graduated rather than abrupt. A critical condition does not result in simulated sudden vehicle immobilization. Instead, the software represents a progressive reduction in simulated vehicle speed toward a safe-stop state.

Because the current study is software-only, this speed-reduction function is a simulation output. No physical throttle, braking system, electronic control unit, or vehicle actuatoris implemented ortested.



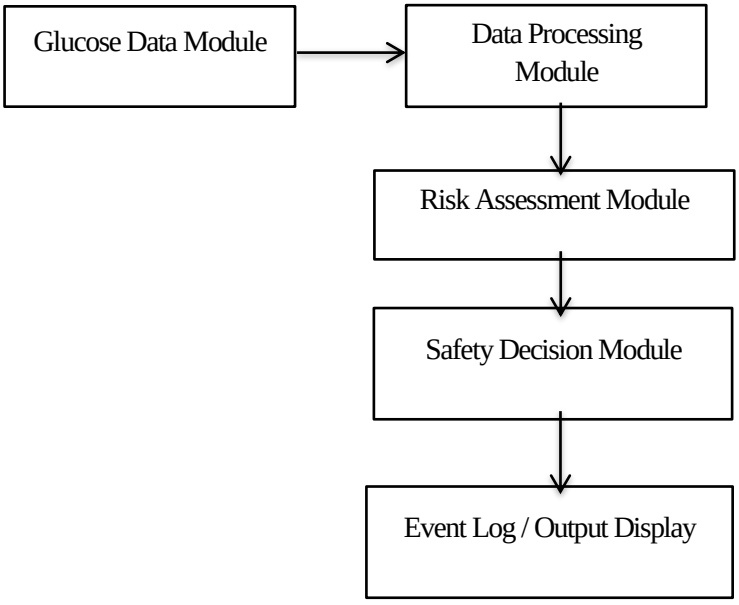
SOFTWARE DESIGN AND IMPLEMENTATION

The proposed framework is implemented as a software simulation consisting of four functional modules:

1. **Glucose Data Module**– receives time-stamped glucose data.
2. **Data Processing Module**– validates and prepares the input data.
3. **Risk Classification Module**– determines the current risk level.
4. **Safety Decision Module**– generates the corresponding software response.

Foreach glucose measurement, the software follows the sequence:

SOFTWARE APPLICATION



The simulation records the glucose value, glucose trend, risk level, warning state, simulated vehicle state, and response time.

The vehicle component is represented computationally rather than through physical hardware. The simulated vehicle can therefore operate in four states: normal, warning, safe-stop recommendation, and gradual speed reduction

SIMULATION AND VALIDATION METHODOLOGY

The proposed framework is evaluated using predefined software simulation scenarios representing different glucose conditions:

1. Stable glucose;
2. Gradual glucose decrease;
3. Rapid glucose decrease;
4. Low-glucose condition;
5. High-glucose condition; and
6. Recovery toward an acceptable condition.

Each scenario is supplied to the system as a sequence of time-stamped glucose measurements.

For every scenario, the system performs the complete processing sequence from glucose input to simulated safety response. The resulting risk classification and response are compared with the expected behaviordefined by the proposed rules.

The evaluation focuses on:

- Correct risk classification;
- Response time;
- Response consistency; and
- False-alarm behavior.

The simulation provides an initial verification of the software decision logic. It does not constitute clinical validation orreal-world vehicle testing.

EXPECTED PERFORMANCE METRICS

The proposed system is evaluated using a small number of measurable performance indicators.

A. Classification Accuracy

Classification accuracy represents the percentage of simulation instances correctly assigned to the expected risk level:

B. Response Time

Response time represents the interval between detection of a risk condition and generation of the corresponding software response.

C. False-Alarm Rate

The false-alarm rate represents the frequency of inappropriate warnings or safety responses underconditions that do not justify intervention.

D. Detection Consistency

Detection consistency evaluates whether repeated presentation of the same glucose condition produces the same risk classification.

These metrics provide a simple basis for evaluating the proposed software framework without implying clinical orreal-world vehicle validation.

DISCUSSION

The proposed framework provides a simple approach for connecting real-time glucose information with vehicle-safety decision making. Its main feature is the combination of current glucose level with temporal trend and persistence rather than relying solely on an isolated glucose measurement.

The four-level risk structure also provides an interpretable relationship between glucose-related risk and software response. Increasing risk results in progressively strongerinterventions, from warnings to a simulated gradual speed-reduction strategy.

The software-only approach provides a controlled and repeatable environment for testing the decision logic before physical implementation. It also allows different glucose scenarios to be reproduced without the cost and complexity of an immediate vehicle prototype.

However, the proposed framework should be considered an initial software proof-of-concept. Simulation results alone cannot establish clinical effectiveness, driver acceptance, orreal-world accident reduction.

LIMITATIONS AND FUTURE WORK

The main limitation of the present study is that the proposed system is evaluated only through software simulation. It is not connected to a physical CGM device or vehicle-control system and has not been tested during real driving.

The simulation also relies on predefined glucose scenarios. Larger and more diverse datasets will be required to evaluate the system under realistic glucose variability and measurement uncertainty.

Future work will focus on integration with real-time CGM data, more advanced vehicle simulation, human-factors evaluation, and eventually controlled physical prototype development.

These developments would allow the proposed framework to progress from a software proof-of-concept toward a more comprehensive glucose-aware vehicle safety system.

CONCLUSION

This paper proposed a software-based glucose-aware vehicle safety framework for supporting safer driving under potentially unsafe glucose conditions. The framework integrates glucose data processing, trend analysis, four-level risk classification, and graduated safety decision making.

Unlike a system based solely on a single glucose measurement, the proposed approach considers the current glucose condition together with its temporal behavior and persistence. The resulting risk level is mapped to a graduated response ranging from normal operation and driver warnings to safe-stop recommendations and simulated gradual speed reduction.

The proposed software architecture provides a controlled environment for evaluating the decision logic through predefined glucose scenarios. The framework does not replace clinical judgment or determine fitness to drive; rather, it is intended as an additional safety layer.

Future integration with real-time CGM devices, vehicle simulation platforms, and controlled physical systems will be required to evaluate the framework under realistic operating conditions.

REFERENCES

[1] International Diabetes Federation, *IDF Diabetes Atlas*, 11th ed. Brussels, Belgium: International Diabetes Federation, 2025.

[2] World Health Organization, *Global Status Report on Road Safety 2023* . Geneva, Switzerland: World Health Organization, 2023.

[3] M. S. Al-Quraishi, S. S. A. Ali, M. Al-Qurishi, T. B. Tang, and S.Elferik, "Technologies
for detecting and monitoring drivers' states: A systematic review,"*Heliyon*, vol. 10, no.
20, Art. no. e39592, 2024,doi: 10.1016/j.heliyon.2024.e39592.

[4] L. Melders, R.Smigins, and A.Birkavs, "Recent advances in vehicle driver health monitoring systems,"*Sensors*, vol. 25, no. 6, Art. no. 1812, 2025,doi: 10.3390/ s25061812.

[5] D. J. Cox*et al.*, "Diabetes and driving: A statement of the American Diabetes Association,"*Diabetes Care*, vol. 47, no. 11, pp. 1889– 1896, 2024.

[6] S. Trawley*et al.*, "Driving with type 1 diabetes: Real-world evidence to support starting glucose level and frequency of monitoring during journeys,"*Diabetes Technol. Ther.*, vol. 24, no. 5, pp. 350–356, 2022,doi: 10.1089/dia.2021.0460.

[7] R. Maeda*et al.*, "Continuous glucose monitoring with low-glucose alerts in insulin-treated drivers with diabetes: A randomized crossover study,"*Diabetes Res. Clin.Pract.*, vol. 222, Art. no. 112074, 2025.

[8] C. Bérubé*et al.*, "Multimodal in-vehicle hypoglycemia warning for drivers with type 1 diabetes: Design and evaluation in simulated and real-world driving," *Factors*, vol. 11, Art. no. e46967, 2024,doi: 10.2196/46967.

[9] A. Amidei*et al.*, "Unobtrusive multimodal monitoring of physiological signals for driver state analysis,"*IEEE Sensors Journal*, vol. 25, no. 5, pp. 7809–7818, 2025,doi: 10.1109/J SEN.2024.3385480.

[10] M.Garrosa, M. Ceccarelli, S. S. Sánchez, and M. Russo, "Design and validation of a low-cost vehicle driver monitoring device,"*Mechanical Systems and Signal Processing*, vol. 235, Art. no. 112939, 2025,doi: 10.1016/j.ymssp.2025.112939.

[11] R. E. Barka and I. Politis, "Driving into the future: A scoping review of smartwatch use for real-time driver monitoring,"*Transportation Research Interdisciplinary Perspectives*, vol. 25, Art. no. 101098, 2024,doi: 10.1016/j.trip.2024.101098.