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Spot Alert: Black Spot Identification & Alerting System

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Abstract:One of the most serious threats to security on roads are accidents that keep occurring nearly on all roads particularly on accident prone specific location also called as "black spot". Providing information for such locations is a good governance initiative but providing the data in non-interactive and static formats through government platforms makes it difficult for the drivers to make best use of information while being on travel. This project intends to develop an intelligent navigation application to ensure improved road safety through alerts and immediate information regarding hazards.

The proposed system is an alternative navigation system that is capable of providing traffic notification, a 3D view of the route, and voice notification to the user whenever the user approaches to accidents, construction site and dangerous places. Moreover, the accidents and construction sites can be updated on the system by authorized users such as police department, and road construction department to provide notified to the user accurately and timely.

The purpose of this project is to assist drivers in becoming aware while being provided actionable and real-time alerts of dangers that reduce the possibility of accidents. Moreover, the integration of navigation technology along with reporting the hazards in real-time builds up a smart and safer infrastructure for transportation.

I. INTRODUCTION

Road transportation plays an important role in our daily life and development of our economy. Road traffic accidents are a serious global issue resulting in a significant number of casualties and losses every year. These accidents are affected by many contributing and co-existing factors, such as driver behavior, vehicle conditions, traffic parameters, road infrastructure, and environmental conditions.

There are certain places on road systems where the accident occurrence is high due to unsafe road designs, difficult traffic situation, inadequate visual condition, etc. Such places are called black spots or accident-prone places. The identification of black spots on the road is important so that the authorities and road users can take precautionary measures and corrective actions to avoid accidents.

Conventional methods of black spot identification are based on accident history and records followed by manual analysis of the data. Such methods are time-consuming and lack real-time data. The proposed project SpotAlert provides a solution for the identification of accident-prone road segments through hazard information collection and analysis. The proposed system aims to provide a platform to maintain hazard information for the road segments in an orderly manner to help drivers navigate safely and help authorities to manage road safety correctly.

II. RELATED WORK

Identifying the locations of roads with a high occurrence of accidents, commonly referred to as black spots, has been the subject of significant research in the field of transportation safety. The conventional methods for determining these black spots primarily depend on statistically analyzing historical accident information. In this analysis, road networks are divided into segments. Following this, the hazardous segments are identified based on accident frequency or severity. The statistical methods utilized for this purpose include accident frequency analysis, severity indices, and Poisson distribution models. However, these methods often exhibit limited capacities in understanding the correlations among various factors contributing to the phenomenon of road accidents.

In light of the above issues, black spot determination techniques based on machine learning algorithm have received significant interest among the researchers. Some machine learning algorithms like logistic regression, k-nearest neighbors, decision trees, neural networks, etc. are applied on vehicle accidents data groups to extract the relationships of road geometrical characteristics and framework factors, traffic environment, and other influences. The empirically black spot analyses contributed by the data techniques can handle a far greater number of data's whether that is high and multi-dimensional.

More recent works have focused on image-based approaches. Using modern methods like deep learning, researchers analyze street view or satellite images. Analyzing information about a given location from the raw features of the surrounding road environment consisting of buildings, vegetation and road structure, it is possible to classify a given location into "safe" or "dangerous." Approaches like these can help us realize that information based on vision and environment can also play a vital role in understanding the hazards of road condition.

The SpotAlert system aims to enhance the accessibility and analysis of dangerous road locations and their corresponding black spots using the accident statistics provided by the local police station.

III. PROPOSED SYSTEM

SpotAlert is a road hazard alert and intelligent navigation support system that leverages location awareness to ensure higher awareness while driving. SpotAlert works on the principle of identifying the accident-prone roads (black spots) where users receive alerts while navigating.

Black Spot referring to the high frequency or severity of an accident at certain places due to specific effects dominated by human, environmental and infrastructural factors [1]. Classical methods to identify black spot use historical accident dataset, statistics and spatial-segmentation. Commonly these methods are not adaptive to road condition at that moment and define statically [4].

SpotAlert overcomes these limitations with automated hazard detection through geospatial analysis and route-filtering so that only the relevant hazard alerts will be sent to the user. This approach is similar to the intelligent transportation systems (ITS), which uses various data sources and machine learning algorithms to enhance safety outcomes [6].

A. Hazard Reporting

The SpotAlert system uses a Hazard reporting mechanism to detect, store and manage the hazardous segments of the road. It uses a hybrid approach of automation and structured hazard modelling.

1) Automatic Hazard Detection

SpotAlert uses open geospatial data from OpenStreetMap (OSM) to autonomously identify potential hazardous accident zones. Unlike conventional systems that use accident history to identify unsafe locations, the geospatial method will allow potential unsafe locations to be identified before incidents occur, enhancing preventive safety.

The system identifies the following types of hazards:

- Schools
- Roundabouts
- Railway level crossings
- Traffic signals

Areas that are considered critical are the interactions that present opportunities for vehicle, and pedestrian conflicts as well as compositional and complex movements. Several studies reveal that the types of intersections, road geometry and surrounding objects and barricades in the environment are key factors for the probability of an accident [2].

2) Hazard Data Representation

All the hazards which are detected are stored in the form of a structured entity in the internal database of the system. This design permits efficient querying, filtering and real-time alert.

Each Hazard entity contains the following attributes:

- Hazard Type (e.g., SCHOOL, SIGNAL)
- Geographical Coordinates (Latitude, Longitude)
- Source (OSM or Administrative input)
- Verification Status (validated or unverified)
- Severity Level (risk classification)

This The above representation can be used as current black spot analysis. Risk level is determined by various parameters such as location, severity, contributing factors, etc. [6].

3) Example Hazard Record

An example of a hazard stored in the database is shown below:

- Type: SCHOOL
- Latitude: 16.6662558
- Longitude: 74.2573722
- Source: OSM
- Verified: True

Such Automatically detected hazard warnings can be perceived as instants of potential hazards where the speed of the approaching vehicle, the distraction levels of the driver, or the presence of pedestrians can determine a crisis.

4) Significance of Automatic Hazard Detection

In contrast to usual black spot detection approach which predict areas based on history of accidents, SpotAlert takes a preventive approach by using predictive modelling to determine dangerous areas based on environmental and infrastructural factors.

Furthermore, prior work has shown that relying on historical accident data alone can miss important underlying casual factors for road safety and delay interventions [1]. SpotAlert integrates real-time spatial information along with context-sensitive characteristics of the road making it possible to pre-emptively determine hazards and provide safer route alternatives.

IV. METHODOLOGY

The methodology for the new SpotAlert system revolves around identification, analysis, and sending of timely information regarding hazards that pose risk to driver safety. The system uses a sorted pipeline for effective data collection, hazard detection, classification, storage, and alert delivery on real-time basis. With the data collection being of black spot identification systems very similar to one's being developed today that encompass statistical methods, machine learning, and spatial analysis to improve effectiveness [6].

A. Data Acquisition

The first phase is data collection from diverse methods to achieve complete hazard coverage. The black-spot identification techniques are presumed with historical accident records. Historical accident records are vulnerable to non-completeness and accessibility [4]. The system architecture proposed in this study makes use of:

Geospatial data from OpenStreetMap (OSM) for detecting infrastructure-based hazards (e.g., schools, signals, crossings)

- Administrative inputs for manually verified accident-prone locations
- (Optional extension) Historical accident datasets for future enhancement

This approach using multiple sources significantely enhances the certainty and comprehensiveness of hazard identification.

B. Hazard Detection and Extraction

The automated detection of hazards is performed through geospatial feature extraction. The tag set contains words through which relevant elements in the map can be extracted:

- highway=traffic_signals
- railway=level_crossing
- amenity=school
- junction=roundabout

Asserted hotspots are high-risk locations, as they are locations where multiple vehicles can meet and have a less straightforward crossing. Some research also shows that the environment of the road can have a big impact on whether an accident can happen & also contains traffic lights, crossings, pedestrian walkways, etc. [1].

Each detected hotspot will be extracted; with its geo locations and which will be passed on to the processing module.

C. Hazard Modelling and Database Design

Each of the hazards are identified and mapped onto a defined data structure for efficient storage and retrieval. A Hazard entity is maintained by the system. The attributes of the Hazard entity is:

- Hazard Type
- Latitude and Longitude

- Source (OSM/Admin)
- Verification Status
- Severity Level

This design allows quick access to attract information and enhances further analytical processing. Other multi-dimensional models are also available in black spot identification systems to assess accidents' prone areas based on various factors [6].

D. Hazard Classification and Severity Analysis

The classification of the danger is made according to the level of risk. In addition to the traditional assessment methods based on the probability of an accident. Recent techniques take into account other attributes like the type of location, traffic flow, and environmental features [4].

Severity levels are categorized as:

- Low Risk – Minor hazards with minimal traffic interaction
- Medium Risk – Moderate complexity (e.g., roundabouts)
- High Risk – Critical zones (e.g., schools, crossings, accident-prone areas)

Future developments could be the integration of some machine learning classifiers such as clustering or Bayesian networks to improve the models' classification accuracy, based on recent studies [6].

E. Route-Based Hazard Filtering

The system filters out the irrelevant hazards based on user's navigation route. The hazards are selected from user's navigation route based on GPS and path matching algorithm. With GPS and path matching algorithm, the system can select hazards that nearby to the user's navigation route based on predetermined buffer distance.

Reducing false-positive incidents informs the users better and makes smart actions for the users to deliver them contextually relevant hazards.

F. Alert Generation and Notification

The last process is to provide the user with near-real-time notifications. When the user is near the location of the hazard specified in the map with a fixed threshold (for example, 200-500 meters), the system sends:

Visual alerts on the navigation interface

Voice-based notifications for hands-free awareness

With such alerts, drivers can take precautions beforehand and prevent accidents.

G. System Workflow

The overall workflow of the system can be summarized as follows:

Data Collection (OSM + Admin input)

Hazard Detection and Extraction

Data Structuring and Storage

Hazard Classification and Severity Assignment

Route-Based Filtering

Real-Time Alert Generation

In conclusion, the integration of geospatial data processing with intelligent hazard warning contributes positively to road safety.

H. Methodological Advantages

The advantages of this proposed approach further add to the significant advantages over Black Spot Detection.

Proactive detection using environmental and map-based data

- Real-time alerting instead of static analysis
- Multi-source data integration for improved accuracy
- Scalability using geospatial databases and APIs

The main aspect that distinguishes our system from other traditional systems is that it is pre-emptive in nature, rather than merely assessing accidents with a history, which is the case with most conventional systems.

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V. SYSTEM INTERFACES AND IMPLEMENTATION RESULTS

The screenshots of the SpotAlert system were captured in order to exemplify the implementation of proposed approach in practice. They showcase the journey from data processing and management to real-time navigation on the front-end side.

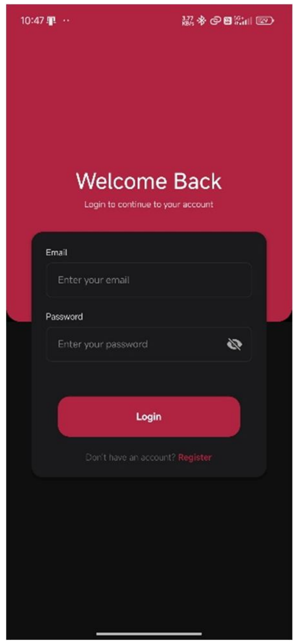

Figure 1: User Authentication and Access Control Interface

SpotAlert's secure user authentication interface. This sign-in portal ensures system confidentiality by limiting access to admin features for authorized personnel only, while allowing authenticated users to safely update hazard information and access data relating to road segment.

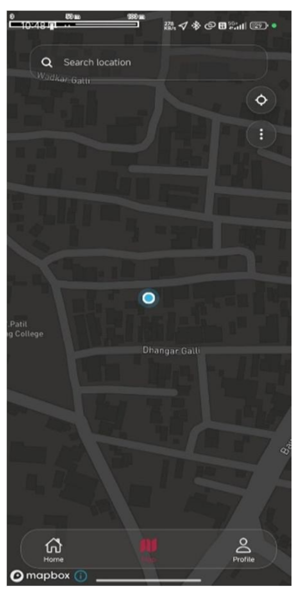

Figure 2: Real-Time Geospatial Navigation Interface

SpotAlert employs a core map interface that includes real-time location tracking. This key image shows the ability to track the user's position within the road network at any given moment. This location-based functionality serves as the basis for its route-based hazard filtering. With route-based hazard filtering, SpotAlert can track whether the user's position is near or close to black spots and other hazardous zones.

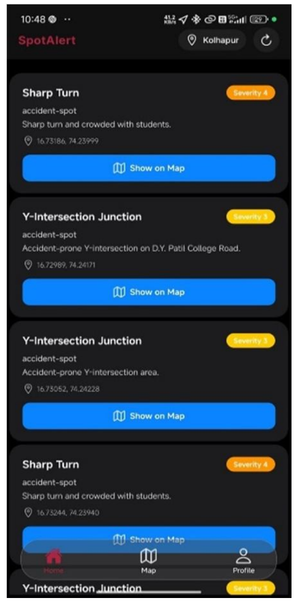

Figure 3: Localized Hazard Classification and Reporting Dashboard

The hazard reporting dashboard with highlighting evaluated risk zones around user. This dashboard is a demonstrated use case of hazard modelling and severity evaluation modules from the proposed system. Each of the identified black spots is treated as an independent entity showcasing its hazard type, geo-co-ordinates, contextual information, along with a severity rank – necessary to convey driver the risk associated with it.

Figure 4: 3D Route Visualization and Proactive Hazard Demarcation

An implementation of SpotAlert is a three-dimensional graphic interface. It uses the visual and practical perception of geospatial data. A persistent red cylinder geofence projects a high-accident region (black spot) directly onto the terrain in the planned route of the user. The graphic interface demonstrates the visual alarm used by the system to enable the driver to have contextual awareness of spatial proximity to the dangerous sections.

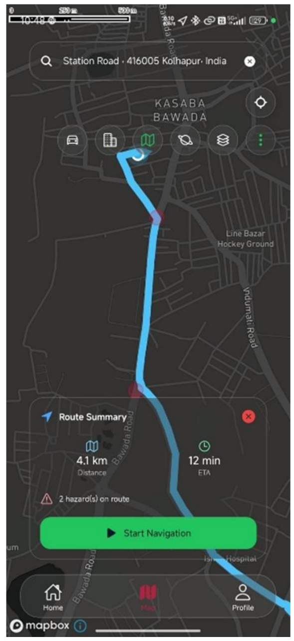

Figure 5: Pre-Navigation Route Summary and Hazard Filtering

SpotAlert's pre-navigation interface, showcasing the route-based design of its hazard filtering algorithm. When the user selects a destination, the underlying system accesses their selected path and performs a query against its internal hazard database. The interface provides a summary of the path for posterity (i.e. driving distance and expected time of arrival (ETA)) whilst advising specific road segments within the selected path where there exists a high density of hazards covered by the SpotAlert application (see red dots highlighting 'danger zones' and the '2 hazard(s) on route' popup). This enables the driver to assess the risk associated with their selected path before initiating travel.

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