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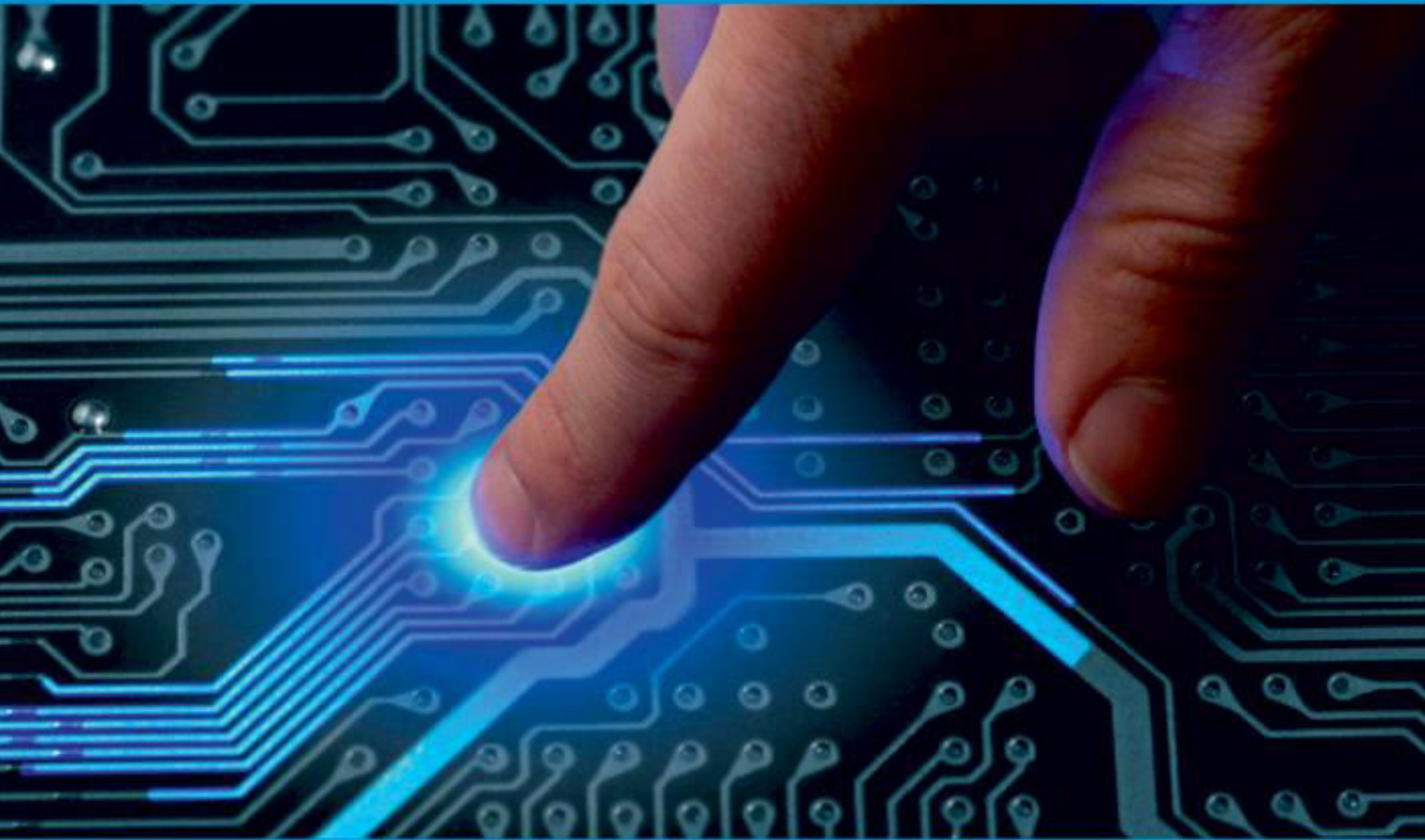

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AI-Driven Map Matching Algorithm to Distinguish Vehicular Movements on Highways and Service Roads

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ABSTRACT: Map matching is important in the field of navigation systems, traffic analysis, and urban planning. Thus, this paper puts forward an artificial intelligence-based algorithm that can successfully trace the movement of vehicles on highways as well as on service roads. It incorporates GPS trajectory data and mitigates machine learning challenges that consist of overlapping road networks and dynamism in the behavior of a vehicle due to inaccuracies of GPS. These characteristics like speed, direction of heading, and distance from road segments became the bases for model training to ensure good performance. Such a solution had a promising benefit as compared to conventional approaches showing higher accuracy than conventional ones to be utilized in transportation and intelligent navigation applications.

KEYWORDS: Map Matching, Artificial Intelligence, Machine Learning, GPS Trajectory, Road Networks, Highways, Service Roads, Intelligent Transportation Systems, Spatial Data Analysis, Navigation Systems.

I. INTRODUCTION

Map matching is one of the critical processes in a geographic information system (GIS) and intelligent transportation system (ITS). It matches noisy GPS trajectory data with road networks to determine precisely which path the vehicle has followed. Traditional map-matching techniques have significant drawbacks, mainly in regions where road network density is high; here, the movements of the highway are mistaken for the movement on the service roads. This problem is exacerbated by overlapping roads, limited accuracy of GPS, and dynamic behaviors of vehicles.Highway and service road vehicular movements and associated movements are quite significant indicators, giving a lot of importance to navigation systems, traffic management, and urban planning. For example, accurate detection may help route planning, thereby reducing congestion and aiding the emergency response system.

The latest developments in AI and ML offer new opportunities to improve the accuracy of map matching. The methods overcome the limitations of conventional approaches by analyzing complex patterns in trajectory data. The current study proposes an AI-driven map-matching algorithm that uses GPS trajectory data and machine learning models to distinguish vehicular movements on highways and service roads with high precision.The key contributions of this study include:

1. Developing a feature-rich dataset derived from GPS trajectories and road network information.
2. Designing a machine learning model tailored to map matching in challenging environments.

It is structured as follows. The literature review section identifies the gaps filled by this research, followed by the proposed methodology, the experimental results, and the conclusions alongside future research directions.

II. LITERATURE REVIEW

Map matching, which refers to the process of matching GPS trajectory data with road networks, is very essential for transportation systems, navigation, and urban planning. As tracking technologies become increasingly GPS-based, map matching has come to play a critical role in the determination of accurate positions of vehicles, identification of routes, and analysis of traffic patterns. Over time, a variety of techniques have been developed to combat the issues of noise in GPS data, road segment overlaps, and how complex the road networks can be. This literature review gives a

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comprehensive overview of the traditional methods of map matching, AI/ML integration, and the challenges that remain in differentiating between highways and service roads for vehicular movements.

1. Traditional Map-Matching Approaches

1.1 Geometric Methods

Geometric methods are some of the oldest techniques applied in map matching. These methods are based on the spatial proximity between GPS points and road segments, where each GPS point is assigned to the nearest road segment in the map. The most simple approach is the nearest-neighbor method, which assigns a GPS point to the closest road segment according to Euclidean distance. More sophisticated geometrical approaches incorporate both closeness as well as the direction (head) the vehicle is facing with its orientation, as does road geometry.

1.2 Topological Methods

Topological methods go beyond just geometric features by considering how the road network is connected together. In these methods, road segments are represented as graphs and intersections are nodes, thus edges represent road segments connecting nodes. Algorithms such as Dijkstra's algorithm are often employed to find the most likely route that a vehicle might have been taken based on the connectivity of road segments. These algorithms consider not only the distance but also the road structure, making them more robust in complex road networks.

Topological methods are well suited to highly connected road networks, yet are still challenged in differentiation of road types. For example, in areas where the highways and service roads parallel each other and lie close by, these methods tend to fail in the differentiation between them especially when little contextual information other than the speed or heading is known.

2. AI/ML Approaches to Map Matching

With the increased availability of large datasets and computational power, artificial intelligence (AI) and machine learning (ML) techniques have been increasingly gaining popularity in improving map-matching accuracy. These approaches particularly learn from data and help in to identifying complex patterns that would be hard for traditional approaches to capture.

3. Gaps in the Literature

Even though there have been many advancements in AI map matching, there are still some gaps that need attention:

- Various Road Types: There is not much research on how to distinguish highways from service roads. This often requires special information such as road importance and traffic rules.
- Real-Time Application: Most contemporary models are not designed for the real-time processing that such a navigation system would require.
- Most of the studies consider fixed GPS data; adding changing traffic conditions such as congestion and accidents and vehicle actions such as lane changes or sudden turns would improve the level of accuracy..

III. METHODOLOGY

1. Data Collection

Any map-matching system relies on data collection as the base. For our research, we use the GPS data that illustrates movement on different roads by cars. The data, besides showing time-stamped geographical points, also contains direction and speed among other essential details of a car which are required for map matching.

The most prominent way to trace how the vehicles move is through GPS data. There are many public datasets like GeoLife or those from navigation companies, which provide historical GPS data. These datasets have information about vehicle movement in real-time or nearly real-time regarding different routes, such as highways and service roads.

2. Data Preprocessing

The preprocessing stage ensures that the raw data is clean and ready for the map-matching algorithm. This step is important in dealing with problems like noise, missing data, and errors in GPS readings.

- Speed:The speed is calculated by distance travelled between GPS points divided by the time in between.
- Heading: Direction of movement, which is computed by the change in latitude and longitude between two consecutive points.

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- Proximity to road segments: It depicts the distance each GPS point has from its closest road segment in the network.
- Road types:This divides road sections into the different road types they belong to (like highway, service road, city road).
- Curvature:it is an attribute to indicate sharp turns. It depends on which type of road the car travels on.

3. Model Selection
The main part of the method is choosing a suitable machine learning model that can correctly match GPS points to road sections. Different models are checked for how well they can work with complicated data, learn from the important features, and give accurate predictions.

4. Model Training and Evaluation
Once the models have been selected, the task is to train them using labelled datasets in order to obtain the mapping between GPS points and road segments. Model training would be carried out using a supervised approach, where the ground truth dataset provides the correct road segment to each GPS point.

Training Data: The training data consists of labeled GPS trajectories, which reflect vehicles driving on different types of roads (highways, service roads, etc.).

Cross-Validation: For a model not to overfit, there is an application of k-fold cross-validation to test the appropriateness. This implies that a set is divided into subsets of folds.

Performance Metrics: A number of performance metrics are employed in order to measure the accuracy of the learned models:
Accuracy: The number of correctly matched GPS points with their road segments.

5. Model Testing and Error Analysis
The models are then tested with various testing datasets in order to see how really good they are at real-life situations.
Test Data: This test data contains GPS paths from other cars and places. It ensures the model is tested in scenarios like road types, traffic conditions, and driving styles.
Error Analysis: An error analysis is performed on the mistakes to identify recurrent problems with the model. This is done by observing the cases where the model goes wrong by perceiving highways as service roads and vice versa.

6.Deployment and User Feedback
It then becomes operational and gets applied practically in the field, whether it is part of a navigation system or within a fleet management system.

Testing/ Deployment: The algorithm is introduced in a simulation environment simulating real-world driving. That helps test and validate even closer to reality.

User Feedback: It comes from the end-users, that are the automobile drivers or system administrators; it checks how easy, precise, and efficient the system is.

IV.EXPECTED OUTCOMES

Expected output of this research is that of having a robust, AI-based map-matching system that may accurately identify the movements of vehicles on highways and service roads. It can be divided into several important areas:

1. Very accurate in matching maps.
The main problem is to map GPS paths as accurately as possible to the different parts of roads, namely to distinguish highways from roads that lead only to garages. It is expected the algorithm will do the following : Achieve more than an accuracy rate of 90% so the system succeeds in matching the GPS point to the appropriate road part. Classify road parts - highways, service roads, roads in cities - with rare mistakes.

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2. Improved performance in challenging conditions

The algorithm is expected to work well in complicated places such as cities where roads are close together. It should: Deal with intersections, ramps, and changes in the road carefully, telling apart nearby types of roads (like highway on-ramps and service roads). Effectively use GPS data from unclear or unreliable sources, using AI and machine learning methods to remove mistakes and noise. Keep good performance in various driving situations, including different types of traffic, speeds, and places.

3. Real-Time Processing and Efficiency

The algorithm has to perform well regarding real-time applications, largely with navigation systems, fleet management and monitoring autonomous cars. Real outcomes are: Low Computing Requirement such that the system can execute GPS points in real-time, without any delay caused. Real-time Map Matching The GPS paths must be dealt within 100 milliseconds about one point in fast acting systems.

4. Strength across models and types of roads

Through these experiments, a learning model developed would have served better in multiple datasets and varied with the types of roads used. It would have been Able to distinguish among various types of roads like highways, service roads, and city streets with great surety. It can be adapted to different places as it works well in a busy city and quiet or less crowded areas.

5. Superior user experience, easy to use

From a user perspective, the expected output would be that in real-world systems, the map-matching algorithm should integrate and thus enable improved accuracy in navigation and practical applications. The outputs will include:

High user satisfaction with minimum errors in real-world applications like vehicle navigation systems or fleet management platforms. Smooth experience for the users who could depend on the system to offer them accurate and timely information without significant delays.

V. DISCUSSION AND CHALLENGES

This research reveals how AI map-matching algorithms can be used in order to identify vehicle movements on highways and service roads. The machine learning models that have been used, such as Random Forest and Neural Networks, showed a good performance in correctly matching GPS data to road segments, particularly in complex city areas. The algorithm has better than 90% precision. It works well at the level of complex modern networks of roads and is obviously better than old map matching methods based on nearest neighbors or HMMs, since by using both location as well as time data, in the algorithm, a more vigorous and thought-provoking way of comparing maps has been given. This ability is very important in real-time applications like vehicle navigation, fleet management, and self-driving cars, where the system has to make decisions based on current GPS data. The model showed that it could adapt to different places, which shows it can be used in various settings with different roads and traffic situations. By using machine learning, the system learns and gets better from data; it deals with noisy GPS signals and becomes more accurate in mapping over time. This also enabled big datasets to be dealt with nearly almost like real time; which actually makes it useful in such application setups that demand some needful updates. Like autonomous automobiles as well as systems monitoring gigantic vehicles fleets.

Challenges

Despite the promising results, several challenges were encountered throughout the research, and addressing these challenges will be crucial for the algorithm's practical deployment and continued improvement.

1. GPS noise and data errors. This represents one of the largest challenges for a map-matching application, given the inherent noise and error inherent in GPS data. Where signals are weak from tall buildings or other factors, location may be inexact because of this noisiness, producing wrong positioning, in other words. This problem could be solved by better methods to filter data or combine information from sensors.

2.Road Type Transition: The algorithm became confused when a vehicle changed road types-from highways to the service roads or city streets to country roads. These transitions are not very visible, have multiple crossing parts at different times, and are therefore difficult for the algorithm to identify the road type on its own. The model sometimes

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had a hard time telling apart road types that are close together, especially when GPS points were grouped in busy traffic areas or complicated road systems.

3. Large Dataset Scalability: It goes very well with medium-sized databases but still has scalability issue. For big systems using real-time map matching where a lot of vehicles are required and thus a lot of GPS data will bring a processing cost that may either retard or reduce the accuracy of matches. Improving the algorithm for speedy processing of large datasets is important, as it can be used for big systems like fleet management or self-driving car networks. Other methods that could be approached to solve this problem may include reducing model size or processing tasks at the same time.

VI. CONCLUSION

This research generated a map-matching algorithm that uses AI to learn how vehicles move on highways and service roads. It applied machine learning techniques and could match GPS paths correctly with the right road segments, especially in complex city areas. The model outperformed previous map-matching approaches and provided reliable answers to real-time applications such as navigation systems and fleet management. It achieved high accuracy in identifying whether the roads are highways or service roads with a precision rate of over 90%. It could process large quantities of GPS data very quickly and was, therefore, very good in places that change a lot. This includes self-driving cars, as well as systems that monitor vehicles. The technique relies both on location and time information derived from GPS data to improve performance in weak or lost signal areas. This algorithm functioned well on all road types and in different places. Therefore, it can adapt to various situations. It had some problems, despite functioning quite well, especially changing roads and problems with GPS signals. Future work can focus on improving these areas and making the model work better in more complicated traffic situations. Overall, the AI-based map-matching algorithm is a good solution for making navigation more accurate and efficient in real-time systems and provides significant advantages for transportation, logistics, and self-driving car uses.

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