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Distance and Bearing Based Vehicle Trajectory Segmentation

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Abstract— Segmentation of a trajectory is the problem of subdividing a trajectory into subparts where each part is homogeneous and expresses similar movement characteristics. We formalize trajectory segmentation problem using likelihood of the distance and bearing parameters. Section of a trajectory is considered homogeneous when distance between trajectory points and angular movement between them are within the user specified threshold value. We developed a framework for trajectory segmentation based on calculating distance and bearing between two trajectory points. An algorithmic framework is presented to segment the trajectory into a minimum number of segments based on the distance and bearing parameters. The algorithm has been tested on real data set.

Keywords— Trajectory segmentation, Bearing based segmentation, Trajectory analysis.

I. INTRODUCTION

With the development of GPS and mobile communication technologies trajectory data are increasingly being available. The analysis of large amounts of trajectory data requires efficient and effective methods to reveal useful patterns. It can be observed through figure 1 that it is hard to compare trajectories in real data sets. Trajectory segmentation is one of the solutions to handle such type of real data sets. Segmentation may be helpful in different applications, like data handling, where efficient storing and searching of data is required or trajectory data analysis where learning about the underlying movement is required. Animal movement study based on segmentation is carried out in Gudmundsson et al. [4] and Shamoun-Baranes et al. [5]. Trajectory segmentation is an approach of partitioning a trajectory into segments that are suitably homogeneous. In the proposed work, we focused on the segmentation of vehicle trajectory data. Subdivision of trajectory, is based on distance and bearing angle between trajectory points. Proposed algorithm uses the *'haversine'* formula to calculate the distance between two trajectory points and Bearing is used to provide angular movements of a trajectory. These two parameters are calculated between trajectory points and a trajectory is segmented at the points where parameters exceed some threshold values. It can be expressed using equation (1).

$$\begin{cases} Distance\ (Pi, Pj) \leq \sigma\ AND\ Bearing(Pi, Pj) \leq \alpha \\ \quad \textbf{\textit{No Segmentation}} \\ Distance\ (Pi, Pj) \geq \sigma\ OR\ Bearing(Pi, Pj) \geq \alpha \\ \quad \textbf{Segmentation at Pj} \end{cases} \quad [-Eq\ 1]$$

Where P_i, P_j are two points of a trajectory. σ and α are distance and bearing threshold respectively.

The Remainder of the paper is organized as follows: Section 1.1 explores the data set used for experiment purpose. Section 1.2 formulates the problem. Section 2 reviews the related literature. Section 3 presents proposed method in detail. In section 4 an experimental evaluation of proposed approach is performed. Finally, Section 5 concludes the paper.

1.1 DATASET

Real data set, School Buses [11] consists of 145 trajectories of 2 school buses collecting (and delivering) students around Athens metropolitan area in Greece for 108 distinct days. For the experimental purpose we worked on 60 trajectories. Figure 1 shows the trajectory path of school bus data.

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Figure 1 : Real Data Set – School Buses Data

1.2 PROBLEM FORMULATION

Let T be any trajectory. Purpose is to subdivide trajectory T into subtrajectories $T_1, T_2, \ldots T_n$ such that trajectory points in each subtrajectory T_i are homogeneous with respect to distance and bearing parameters.

Definition 1 (Trajectory)

A trajectory is a trace generated by a moving object in geographical spaces, usually represented by a series of chronologically ordered points, $\{(x_0,y_0,t_0),...,(x_n, y_n, t_n)\}$ where $(x_i, y_i,)$ are positions of moving objects, t_i is a time stamp, for $i = 0,1,...,n$ and $t_0 < t_1 < ... < t_n$.

Definition 2 (Distance)

'Haversine' formula is used to calculate the great-circle distance between two points – that is, the shortest distance over the earth's surface.

The 'Haversine' Formula to calculate the distance between two points is using equation 2.

$$a = \sin^2(\Delta\varphi/2) + \cos\varphi_1 \cdot \cos\varphi_2 \cdot \sin^2(\Delta\lambda/2)$$

$$c = 2 \cdot \operatorname{atan2}(\sqrt{a}, \sqrt{(1-a)})$$

$$d = R \cdot c$$

$$[-Eq\ 2]$$

Where

φ is latitude

λ is longitude

R is earth's radius

Definition 3 (Bearing)

Bearing is used to define navigation. Bearing can be defined as direction or an angle, between the north-south line of earth or meridian and the line connecting the target and the reference point.

Formula to calculate bearing between two points is defined in equation 3.

$$\theta = \operatorname{atan2}(\sin\Delta\lambda \cdot \cos\varphi_2 , \cos\varphi_1 \cdot \sin\varphi_2 - \sin\varphi_1 \cdot \cos\varphi_2 \cdot \cos\Delta\lambda)$$

$$[-Eq\ 3]$$

Where

φ is latitude

λ is longitude

II. RELATED WORK

Segmentation is generally defined as the partitioning of data into homogeneous, possibly meaningful pieces. Anagnostopoulos et al. [1] motivated the need for global distance oriented segmentation techniques. They presented distance based segmentation algorithms that operate at various scales of computational granularities. Introduced a variance based hybrid variation that can provide an excellent compromise between running time and approximation quality. Buchin et al. [2] developed a framework that computes a segmentation given a decreasing monotone criterion, that is a criterion which, if it holds on a certain segment, also holds on every subsegment of that segment. Buchin et al. [3] introduced criteria-based segmentation used for classification, by using multiple criteria, one for each class. This setting has been successfully applied to a data set of migrating geese. Giannotti et al. [6] discovered a novel form of spatio-temporal pattern, called as a trajectory pattern, represents a set of individual trajectories that share the property of visiting the same sequence of places with similar travel times. Two notions are central to this paper: (i) the regions of interest in the given space, and (ii) the typical travel time of moving objects from region to region. Mann et al. [7] used heuristics such as split-and-merge to find the best segmentation. For ordered data such as trajectories the global segmentation achieved by dynamic programming. Keogh et al. [8] carried out extensive review and empirical comparison of time series segmentation algorithms from a data mining perspective. The authors Keogh et al. [8] have discussed the most popular approach, Sliding Windows produces very poor results, and Top-Down, can produce reasonable results, it does not scale well. In contrast, the least well known, Bottom-Up, approach produces excellent results and scales linearly with the size of the dataset. Kang et al. [9] Mines spatiotemporal frequent patterns. Uses line simplification and clustering to discover spatiotemporal regions and extracts spatiotemporal frequent patterns in prefix-projection approach. Cheng et al. [10] Introduces a feature-centered mining approach that generates discriminative patterns sequentially on a progressively shrinking FP-tree by incrementally eliminating training instances. Mirge et al. [12] introduced algorithm to mine trajectory patterns in order to identify heavy traffic patterns in road network.

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III. PROPOSED SEGMENTATION METHOD

We present a novel algorithm for trajectory segmentation based on parameters, distance and bearing, which computes an efficient segmentation for vehicle trajectory.

Proposed algorithm finds the distance and bearing angle between every two continuous points for a trajectory. If either the distance exceeds the distance threshold or bearing angle exceeds the bearing threshold, then these consecutive points are considered non-homogeneous with respect to distance or bearing and trajectory is segmented at one of these points. The bearing angle gives an angular movement of the vehicle. Proposed algorithm checked the angular movement i.e. bearing at every point and if it crosses threshold limit of bearing angle, trajectory is cut at corresponding points. Similarly check has also been made for distance. If trajectory point is farther away from its neighbor i.e. distance with the neighbor is higher than distance threshold then also trajectory is segmented at such points.

Figure 2 shows the trajectory segmented at the places where the likelihood of distant or bearing parameters exceeds the threshold value. In the figure $t_1, t_2, \ldots t_6$ represents the sub-trajectories of trajectory T. Points where the trajectory is segmented is represented using red colour.

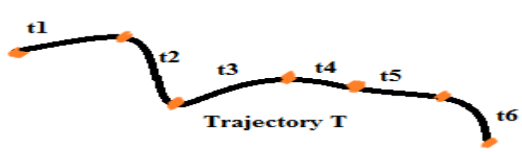

Figure 2: Segmented Trajectory

3.1 Algorithmic Framework

3.1.1. Trajectory Segmentation

Trajectory Segmentation requires to find the distance and bearing between two consecutive points in the trajectory if these values exceed the distance threshold σ or bearing threshold α segmentation takes place. Otherwise, no segmentation is done. Further next point in the trajectory is used to check for the same. In the algorithm *Trajec_seg* firstly start point of the trajectory is taken as the first point of the segment, then for next point distance and bearing are calculated and checked against σ and α respectively. If any of the value exceeds the respective threshold value, the trajectory is segmented at this point otherwise the same procedure is repeated for the current point and the next point.

Algorithm- Trajec_Seg (T, σ, α) An Algorithm for segmenting Trajectory.

Input :

Trajectory T ={L_1, L_2, L_3… L_n} where L_i is location of vehicle at a particular moment and represented as L_i = {Lat_i, Lon_i) in which Lat_i, $Long_i$ are latitude and longitude respectively. Distance threshold σ, Bearing Threshold α.

Output :
Set of trajectory segments : T_s
Procedure :
Begin

1. Set L_1 as start point for segmentation.
2. $T_s \leftarrow L_1$
3. **for** each $L_i \in$ T where i=1 to n do
4. Calculate D ←Distance (L_i, L_{i+1})
5. Calculate B ←Bearing (L_i, L_{i+1})
6. **If** $(D \geq \sigma)$ OR $(B \geq \alpha)$
7. Cut trajectory T at L_{i+1}. // **segmentation**
8. Ts ← L_{i+1}
9. **Else**
10. No segmentation // **Continue with next location**
11. **End for.**

3.1.2 Haversine Distance Calculation

Algorithm uses 'Haversine' formula *(Def2)* to calculate the great circle distance between two points in the earth's surface.

Algorithm- Distance (L_i, L_j) An Algorithm for calculating Haversine distance between two Locations.

Input:
Two Locations L_i (Lat_i, Lon_i) and L_j (Lat_j, Lon_j)
Output:
Haversine Distance D.

Procedure :
Begin

1. Set R = 6371000. // metres
2. Calculate $\Delta\varphi \leftarrow lat_j - lat_i$.
3. Calculate $\Delta\lambda \leftarrow lon_j - lon_i$
4. Calculate a ← $\sin^2(\Delta\varphi/2) + \cos Lat_i * \cos Lat_j * \sin^2(\Delta\lambda/2)$.
5. Calculate c ← 2 * atan2(√a, √(1−a)).
6. Calculate D← R * c.

3.1.3 Bearing Calculation

Bearing gives the angular movement of the trajectory. It can be defined as an angle, between the north-south line of earth or meridian and the line connecting the target and the reference point. Formula to calculate bearing has been applied in the algorithm '*Bearing'*.

Algorithm- Bearing (L_i, L_j) An Algorithm for calculating Bearing angle between two Locations.

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Input:
Two Locations L_i (Lat_i, Lon_i) and L_j (Lat_j, Lon_j)
Output:
Bearing B.

Procedure :
Begin
1. Calculate $\Delta\varphi \leftarrow lat_j - lat_i$.
2. Calculate $\Delta\lambda \leftarrow lon_j - lon_i$
3. Calculate M $\leftarrow$ $\sin \Delta\lambda * \cos lat_j$
4. Calculate N $\leftarrow$($\cos Lat_i * \sin Lat_j$) – ($\sin Lat_i * \cos Lat_j * \cos \Delta\lambda$)
5. Calculate B $\leftarrow$ atan2(M, N)

IV. EXPERIMENT RESULT

Experiment has been performed on real data set - School [11]. It consists of trajectories of 2 school buses collecting (and delivering) students around the Athens metropolitan area in Greece. For the experiment purpose part of the data set has been taken which consists of 60 trajectories.
For experimentation in our framework, we implemented the proposed algorithm in MATLAB. Experiments were performed on Pentium IV machine with 500 GB Hard disk and 1 GB RAM.

4.1 Result of algorithm Trajec_Seg

Figure 3 represents the normal trajectory while figure 4 represents the outcome of the experimentation of the algorithm *Trajec_Seg*. As it can be observed through the figure 4 that trajectory has been segmented at the locations (represented by blue mark) where bearing (angular movement) and distance between trajectory points crosses their threshold limit. Here threshold for the distance σ and bearing α is taken as the average distance and average bearing between all trajectory points respectively. For figure 4, σ = 115.70069 α= 122.97307.

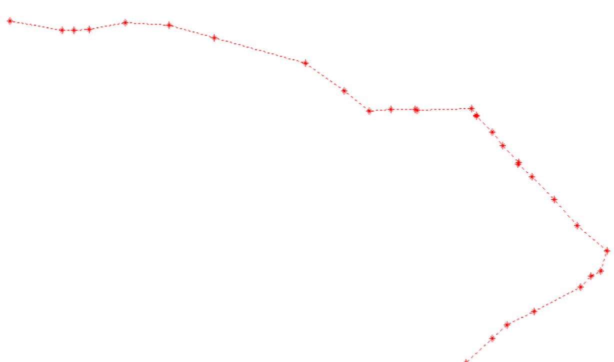

Figure 3: Normal Trajectory

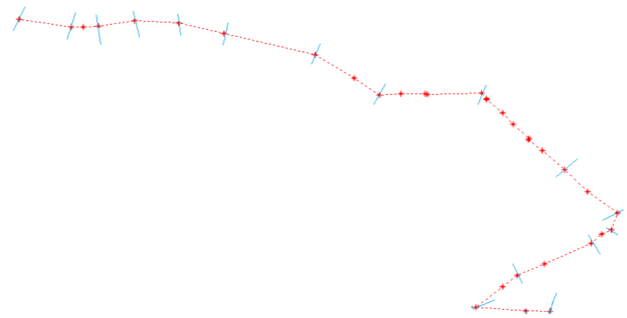

Figure 4: Segmented Trajectory

4.2 Accuracy of the algorithm Trajec_Seg Accuracy of the result has been checked by making the contingency matrix and its corresponding contingency table as shown in the Table 1 and in Table 2. Experiment has been performed with 40 trajectories. Results of *Trajec_Seg* are compared with the actual classes of segmentation places. Four parameters true positive, true negative, false positive, false negative are evaluated. Based on these parameters different measures to check the accuracy of the result has been carried out. Result is shown in Table 3 which illustrates that mostly segmentation has done at correct places. There is less number of times segmentation has done at the normal places.

Number of trajectories 40, distance threshold σ = 115.70069, bearing threshold α= 122.97307.

Table 1 Contingency Matrix for Trajec_Seg

	Segmentation Done Accurately	**Segmentation Not Done**
Actual Segmentations	594 times	52 times
No Segmentation (Normal Points)	65 times	7411 times

Table 2 Contingency Table for Trajec_Seg

TRUE POSITIVE(TP) Segmentation done at correct Places	**FALSE NEGATIVE(FN) Segmentation not done at the actual places**	**P (Actual Segmentation)**
594	**52**	**646**
FALSE POSITIVE(FP) Normal Points Incorrectly segmented	**TRUE NEGATIVE(TN) Normal Points not segmented**	**N (Segmentation not required)**
65	**7411**	**7476**

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Table 3 Accuracy of *Trajec_Seg*

Performance Measure	*Trajec_Seg*
TPR	.9195
TNR	.9913
PPV	.9013
NPV	.9930
FNR	.0804
FPR	.0086
FDR	.0986
FOR	.00696
ACC	.9855
F1	.9103
MK	.8943
BM	.9108

V. CONCLUSIONS

This paper presented a Novel framework which allows efficient segmentation using two parameters distance and bearing. Both parameters perfectly suited for real world applications like vehicle traffic management. Work has been tested for real dataset, School Buses, for the different values of parameters. Results from experiments show that the proposed method achieved good accuracy. The only limitation of this algorithm is that some more parameters like speed etc can be added to get more realistic results.

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