Map Matching Algorithm: Empirical Review Based on Indian OpenStreetMap Road Network Data

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Abstract: *Locating devices on the road network is crucial for any location-based system. Accuracy of map matching algorithms may highly affect the accuracy of any location-based service. This paper includes an empirical review of five major map matching algorithms for locating a device on a digital road network. A standard dataset was used to simulate the working of map matching algorithms. After ascertaining the accuracy of map matching algorithms, it was tested on a real road network. Six different routes varying from 0.6 kilometers to 32 kilometers, covering a total distance of 82.2 kilometers were included in the experiment. Performance of map matching algorithms was evaluated on a total of 2094 road nodes with 1271070 Global Positioning System (GPS) points on the basis of matched, unmatched nodes with root mean square error. It was concluded that Hidden-Markov Model based map matching algorithms has reasonably good accuracy (96% using global data and 89% using Indian dataset) and execution time in comparison to geometric, topological, Kalman filter and Frechet distance based algorithms.*

Keywords: *Hidden markov model, kalman filter, frechet distance, OSM, GPS.*

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1. Introduction

Global Navigation Satellite System (GNSS) and digital maps are fundamental to any navigation system. A digital map could be assumed as a virtual representation of any geographic area detailing roads, topography, climates and political boundaries. The user's location on the digital map is marked through the process of map matching. Map matching is a method to use digital maps and GNSS signals to locate a user on digital map [34]. The geographical database, geo-location information, map matching algorithm, and routing information are the main components of a navigation system. Using observed coordinates, map matching algorithms estimate the path taken by an entity. Accuracy of map matching algorithms may impede because of inaccurate GNSS fix or complex road networks [27, 28, 39]. Further, the type of navigation system on which map matching is to be deployed may also affect its performance.

For instance, online systems can immediately locate any nodes on digital road network whenever a Global Positioning System (GPS) fix is obtained; on the other hand, offline systems batch process the entire input trajectory before calculating the route. Skyscrapers, dense tree cover, and tunnels may induce errors in GNSS fix and may provide contradictory navigation guidelines. Map matching algorithms have recently been inducted to various location-based services like traffic management, fleet management, and route optimization, etc., The inherent challenge for any map matching algorithm is select a road segment, which is either nearest to the GPS points or a road, which is frequently traversed by users. Some map matching methods consider only distance and it leads to wrong routes which are less frequently travelled by users. Although numerous reviews are available citing the evolution, challenges, and performance of map matching algorithms, yet they lack a tinge of empirical evaluation on a single dataset. Further, most of the literature available has explored and promulgated the accuracy and performance of online map matching algorithms only. As per available literature and to the best of our knowledge, very few studies have examined the performance of offline map matching algorithms. In reference to previously stated observations, an empirical evaluation of map matching algorithms for offline navigation systems may significantly contribute towards existing research literature [3, 4, 5, 11, 35].

In this paper, provide brief information about the localization and map matching algorithms used in navigation system. In this paper an attempt has been made to empirically evaluate their performance for offline navigation systems through case analysis. Rest of this paper is organized as follows; Section 2 provides brief information about existing literature of map matching algorithms. Experimental design and case analysis presented in sections 3 and 4 respectively. Section 5 includes results and discussion and section 6 concludes the manuscript.

2. Literature Survey

Formally map matching problem can be defined in terms of graph theory; where graph $G(N,R)$ is a digital road network; N is node in the road network. R is road or link, which connects two or more nodes in the road network. The sequence of GNSS traces of vehicle is denoted as $O = (O_t \mid t = 1,2,3,T)$; where O_t is GNSS receiver output at time t and is composed of longitude, latitude and time stamp information. Map matching algorithm calculates the actual position of vehicle on digital road network G by mapping O_t with N and R. The output of map matching algorithm is $M = (M_i \mid i = 1,2,3,n)$ where M $\in R$.

As per the existing paradigms of the research community, the literature reviewed is categorized into geometric, topological, Probabilistic, and advanced map matching algorithms as detailed in following subsections [5, 34]. Geometric map matching is basic and core map matching algorithm category. First map matching concept was proposed by Bernstein and Kornh a user for identify the location of a geographical entity or moving vehicle on digital road network [6]. This concept was based on the distance between two points. Later refinement in their basic concept was introduced using point to point, point to curve and curve to curve approach [14, 40]. Improvement in the category of geometric map matching algorithm was proposed by combining the output of inertial sensor with GNSS output, differential GPS output [12]. Further geometric algorithms like point to point and point to curve were modified by combining speed information of vehicle, road design and historical information, verification process [16, 17, 27].

The basic topological algorithm considered all topological features (like turn information, direction information, connectivity, and containment information of the road network). Enhancement in the basic topological algorithm was made by using the concept of weighted parameter selection [30]. Further topological algorithm was enhanced by using Qualitative Decision Making (QDM) process. Further, the performance of topological map matching algorithm was improved by using GPS data, road type, track information, dead-reckoning, sensors data, and digital elevation model [10, 12, 13, 14, 19, 20, 21, 22, 36].

The probabilistic map matching algorithm maps the positional fix to the digital map by defining a rectangular or elliptical region around the positional fix obtained from GNSS receiver or sensor data. The concept of probability model suggested the possible region for the inaccuracies in the mapping process. These inaccuracies can be due to variation in sampling interval GPS receiver output and quality of signal received [7, 10, 25]. Further, the probability theory was deployed using the emission and transition probability in map matching problems. These emission and transition probabilities are incorporated with Hidden Markov Model (HMM) [23, 24, 33, 37].

Advanced map matching algorithm incorporates some additional models and processing algorithm to enhance the performance and accuracy of mapping process. The advanced map matching algorithms evolved by combining geometric data with advanced approaches like Kalman filter, Dempster Shafer theory, Belief Theory, deferential GNSS with ABS (Anti-Lock Braking) sensors, voting method, JaroWinklers String-matching technique, path interference filtering, inertial sensor, genetic algorithm, ant cloning, voting technique, DS theory and energy efficient techniques [9, 15, 18, 26, 28, 29, 30, 31, 32, 38, 39].

3. Experiment Design

A typical map matching procedure is shown in Figure 1. Consider a road network of 6 roads and two GPS receiver outputs as G1 and G2. Point G1 is nearest to one road that is Road 4, so it can be easily to road node F11(of Road 4). On the contrary, point F2 has three edges near to it, i.e., road 3, road 5, and road 6. The prime challenge for any map matching algorithm is to decide best GNSS fix amongst three nearest options (F21, F22, and F23).

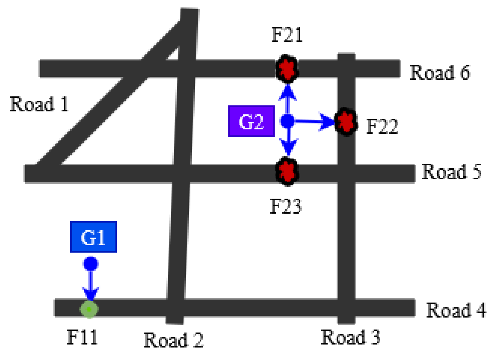

Figure 1. Typical GNSS fix and working of map matching algorithm.

In this paper, the performance of five map matching algorithms named Frechet distance, Hidden Markov Model, Kalman filter, Point to Point (P2P) geometric and basic topological based map matching algorithms are discussed and deployed during experimentation [2, 8]. These algorithms were evaluated on the Matched/ Unmatched node Count (MaUC), accuracy ratio, and Root Mean Square Error (RMSE).

4. Case Analysis

Dataset recommended by [13] was used to evaluate the accuracy and performance of identified map matching algorithms. This dataset has 247251 points on a road network of 2695 kilometers. Observed performance of various algorithms on [13] dataset is briefed in Table 2. Being a standard dataset, data quality issues could have effectively addressed in it.

Finding an outlier in such dataset is a cumbersome job as it may demand actual traversal of road networks [1, 21].

Further, variance in sampling rate could potentially impact the accuracy of the map matching process. Variance in spatial attributes of rural and urban road networks too may hamper the performance of map matching algorithms. In reference to the aforementioned arguments, a case analysis was undertaken using Open Street Map (OSM) dataset for Indian sub-continent. A custom android application was developed to collect the test data within a bounding box (lat: 30.8020, lon: 76.3577) and (lat: 30.2057, lon: 76.9482). Six different routes of length 0.6 kilometers to 32 kilometers were considered for data collection. Each route was traverse multiple time and trajectory files were created. Total distance of six routes was 82.2 kilometers. Number of trajectories indicates traversal count of each route. For example, route no 1 have length of 1.7 KM with 340 nodes and this road was traversed 30 times and during traversal GPS receiver readings were captures (i.e., 13500 GPS point). Same process was repeated for each route. Total 2094 road nodes (48110 nodes i.e., cumulative sum of nodes considered for each trajectory) and 1271070 GPS points were collected using Android application. Detailed specifications of the routes are given in Table 1.

Table 1. Specification of considered routes and recorded GPS trajectories of Indian sub-continent data.

Route No.	Nodes Count	Route Length	Route starting point as lat, lon (in degree unit)	Route ending point as lat, lon (in degree unit)	Number of trajectories	Cumulative sum of node count	Total count of GPS point	Maximum Speed
1	340	1.7 KM	29.966812, 76.835096	29.965622, 76.851576	30	10200	13500	18
2	270	32 KM	30.343022, 76.845367	30.528030, 76.671989	20	5400	100920	70
3	130	0.6 KM	30.513606, 76.658823	30.516555, 76.660209	20	2600	6460	18
4	547	4.8 KM	30.298053, 76.844670	30.338618, 76.830285	20	10940	18420	40
5	524	15.5 KM	30.495610, 76.604656	30.471645, 76.574952	20	10480	79860	70
6	283	27.7 KM	30.344076, 76.434494	30.493223, 76.579035	30	8490	151910	70

5. Results and Discussion

The output of map matching algorithms on test data recorded on straight road at slow speed is shown in Figure 2. As per observed results, HMM-based map matching algorithm outperformed others. Unlike HMM most algorithms attained marginal accuracy at the turn around curves. The experiment reveals that Geometric map matching algorithm gave the worst results. Topological and HMM-based map matching algorithms gave promising results in dense areas (the area where the density of GPS point per unit was high). Figure 2-f) and Figure 2-c) shows the actual mapping of GPS trajectories using HMM-based and basic topological map matching algorithms respectively.

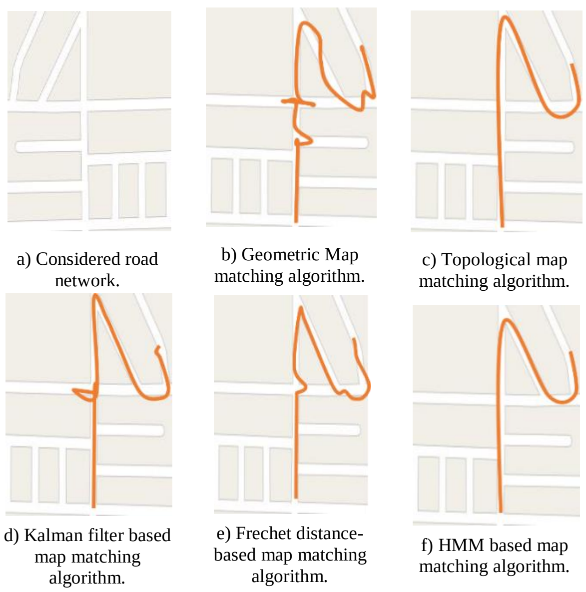

Figure 2. Mapping outputs of selected map matching algorithms on the same GPS and road data.

RMSE of selected five map matching algorithms as recorded during the experiment on global test data and from within the bounding box are shown in Table 2. RMSE gives the error while mapping two data series. As observed, HMM has the lowest RMSE in comparison to other algorithms. P2P based geometric algorithm has high RMSE value and provides highly deviated route from the actual route. MaUC based comparison of map matching algorithms is shown in Table 2. MaUC provide count of data points correctly mapped. As observed during the experiment, HMM-based map matching gave the best results in comparison to other algorithms. The P2P algorithm gave worst results, whereas the Kalman filter based map matching algorithm was found to be better than Frechet distance and topological algorithms.

Accuracy ratio provides mapping accuracy of an algorithm. Accuracy of selected algorithm is shown in Table 2. According to accuracy ratio, HMM-based algorithm has higher accuracy in comparison to other algorithms.Point to point algorithm uses distance as a single parameter for matching so it creates inaccurate results at junctions, adjacent nodes, and areas having poor internet signals. Whereas HMM model uses complex probability theory using the Markov model and provides better results. In HMM model emission and transition probability matrix generate huge mapping candidates and then the complete model provides the best mapping results. From RMSE, MaUC, and accuracy ratio, it has been observed that for better mapping result road information, vehicle information and reference data are required with GPS position fix. Further to analyse the accuracy of considered algorithms based on area type, trajectories were segregated into rural and urban areas. As discussed previously, global dataset [18] does not differentiate between rural and urban areas so Indian dataset was used. The positional accuracy based on rural and urban segregation is shown in Figure 3.

Table 2. Comparison of map matching algorithm based upon RMSE, accuracy ratio and MAUC.

Map Matching Algorithm	Indian dataset from within bounding box						Global dataset [22]			
	Matched Node percentage	Unmatched Node percentage	Accuracy ratio	RMSE at fast speed	RMSE at slow speed	Average RMSE	Matched Node percentage	Unmatched Node percentage	Accuracy ratio	RMSE
Geometric(P2P)	56.41%	44.59%	0.6	0.78	0.64	0.71	78.56%	22.90%	0.79	0.55
Topological	63.19%	34.81%	0.64	0.57	0.51	0.54	84.60%	15.50%	0.87	0.47
Kalman Filter based	81.72%	18.28%	0.82	0.16	0.11	0.13	92%	7.39%	0.92	0.12
HMM-based	89.27%	11.73%	0.89	0.05	0.03	0.04	93.90%	6.00%	0.96	0.04
Frechet Distance based	80.87%	19.13%	0.8	0.33	0.24	0.29	91.43%	8.45%	0.92	0.22

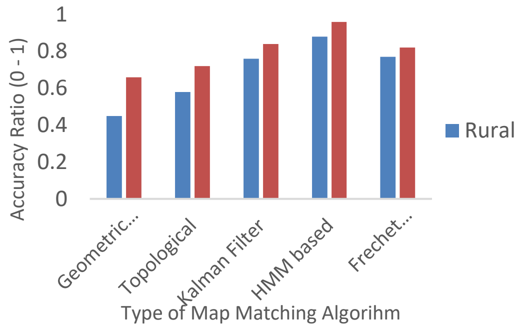

Figure 3. Comparison of selected map matching algorithms based upon the urban and rural road network.

As per observed results, every algorithm has better accuracy in urban areas in comparison to rural areas and HMM obtained proficiency of 96% and 88% in urban and rural areas respectively. From this area-based analysis we can conclude that, this poor accuracy can be due to lack of GPS data in rural area. To achieve high mapping accuracy, GPS and some other non-GPS based localization method must be used. Second accuracy analysis was based upon the sampling interval. In this experiment, the GPS sampling interval varied between 1-5 seconds. If the sampling interval is low, then recorded GPS points would be highly dense and vice versa. HMM and Kalman filter-based algorithm attained better accuracy in comparison to other algorithms, as shown in Figure 4. To achieve good accuracy sufficient GPS data must be present. In case of high GPS receiving interval, GPS points were very far away and few locations were missed out. So, for missing locations information, map matching algorithms provided incorrect results.

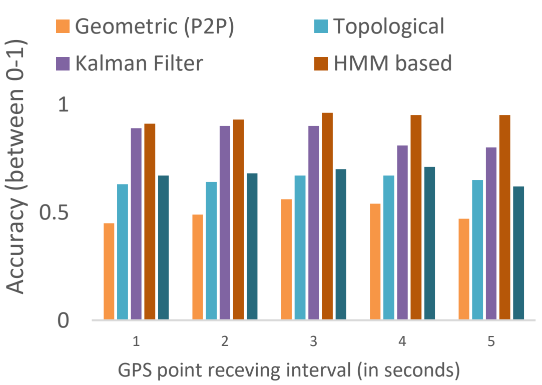

Figure 4. Comparison of selected map matching algorithms based upon GPS point receiving interval.

Comparison of considered map matching algorithms based upon the execution time is shown in Figure 5. In this comparison effect of number of GPS point on algorithm execution was identified. According to this comparison, P2P algorithm had the lowest execution time, and Kalman filter had highest execution time. With increase in number of nodes, execution time also increasing. Below node count 100, all algorithms have approximately the same execution time, but after node count 100, there exists a noticeable difference in the execution time.

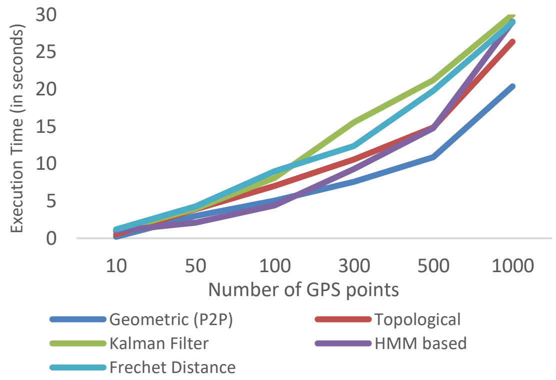

Figure 5. Analysis of effect of number of GPS nodes on the execution time of considered map matching algorithms.

According to performed comparison, it was analyzed that HMM-based map matching algorithm provides good mapping accuracy but required extra processing with moderate execution time in contrast to other algorithms. Two level filtering contributed to enhancing the accuracy of the Kalman filter approach. Despite good accuracy, the execution time of the Kalman filter algorithm is high. As topological information of road network and vehicle were required for computation of topological algorithms, so basic topological algorithm provided more accurate results than P2P algorithm. The incorporation of vehicle speed and direction of travel in the topological method increased the algorithm's accuracy at turn points and curved regions. In comparison to the Point to point algorithm, the Frechet distance method achieved great accuracy, although the calculation of free space diagram needed more processing. Although the point-to-point method produced substantially faster results, but had comparatively poor accuracy. There is a big tradeoff between accuracy and system execution time of any map matching algorithm. If we increase the accuracy, then system execution time may get affected.

6. Conclusions

The findings of the experimental study show that the performance of a road navigation system highly depends on the map matching algorithms used, and the quality of GPS receiver data used. The experimental study evaluated the execution time and accuracy of topological, geometric P2P, Kalman filter based P2P, HMM, Frechet distance map matching algorithms on global and local datasets. As per results, topological map matching algorithms has better performance in comparison to P2P and Frechet distance-based algorithms. Similarly, HMM and Kalman filter based algorithm has good accuracy (96% and 92% respectively for global dataset and 89% and 82% respectively for Indian dataset) in comparison to the other three algorithms. HMM, based algorithm attained high accuracy and average execution time for rural and urban areas. From the results, it has been observed that if GPS points are dense, then the execution time of the system would also be high. On the other hand, if the sampling interval is less, then densely recorded GPS points would lead to the high system execution time.

Further, if the sampling interval is too high, then the density of GPS points will be less and which would lead to lower system accuracy. At high sampling interval, the system gets sparse GPS data; this sparse GPS data is difficult to map at accurate position and results in low system accuracy. If we consider high system accuracy, then HMM-based algorithm is the best option to be considered for both rural and urban area. This paper concludes that accuracy of map matching algorithm is very important for the navigation and that can be improved by using appropriate input from vehicle information, road network components and GPS receiver. Based on this analysis, in future we can a new map matching algorithm that can provide better accuracy and execution time.

References

[1] Ali A. and Schmid F., "Data Quality Assurance for Volunteered Geographic Information," *in Proceedings of International Conference on Geographic Information Science*, Vienna, pp. 126-141, 2014.

[2] Alt H. and Godau M., "Computing the Fréchet Distance Between Two Polygonal Curves," *International Journal of Computational Geometry and Applications*, vol. 5, no. 1, pp. 75-91, 1995.

[3] Arregui H., Loyo E., Otaegui O., and Arbelaitz O., "Impact of The Road Network Configuration on Map-Matching Algorithms for FCD in Urban Environments," *IET Intelligent Transport Systems*, vol. 12, no. 1, pp. 12-21, 2018.

[4] Asadi R., Kareem S., Asadi M. and Asadi S., "An Unsupervised Feed Forward Neural Network Method for Efficient Clustering," *The International Arab Journal of Information Technology*, vol. 14, no. 4, pp. 436-441, 2017.

[5] Atia M., Hilal A., Stellings C., Hartwell E., Toonstra J., Miners W., and Basir O., "A Low-Cost Lane-Determination System Using GNSS/IMU Fusion and HMM-Based Multistage Map Matching," *IEEE Transactions on Intelligent Transportation Systems*, vol. 18, no. 11, pp. 3027-3037, 2017.

[6] Bernstein D. and Kornhauser A., *An Introduction to Map Matching for Personal Navigation Assistants*, New Jersey TIDE Center, New Jersey, 1998.

[7] Bierlaire M., Chen J., and Newman J., "A Probabilistic Map Matching Method for Smartphone GPS Data," *Transportation Research Part C: Emerging Technologies*, vol. 26, pp. 78-98, 2013.

[8] El Najjar M. and Bonnifait P., "A Road-Matching Method for Precise Vehicle Localization Using Belief Theory and Kalman Filtering," *Autonomous Robots*, vol. 19, no. 2, pp. 173-191, 2005.

[9] Gong Y., Chen E., Zhang X., Ni L., and Zhang J., "AntMapper: An ant Colony-Based Map Matching Approach for Trajectory-Based Applications," *IEEE Transactions on Intelligent Transportation Systems*, vol. 19, no. 2, pp. 390-401, 2017.

[10] Jagadeesh G. and Srikanthan T., "Online Map-Matching of Noisy and Sparse Location Data With Hidden Markov and Route Choice Models," *IEEE Transactions on Intelligent Transportation Systems*, vol. 18, no. 9 pp. 2423-2434, 2017.

[11] Kassas Z., Maaref M., Morales J., Khalife J., and Shamei K., "Robust Vehicular Localization and Map Matching in Urban Environments Through IMU, GNSS, and Cellular Signals," *IEEE Intelligent Transportation Systems Magazine*, vol. 12, no. 3, pp. 36-52, 2020.

[12] Kim W., Jee G., and Lee J., "Efficient Use of Digital Road Map in Various Positioning for ITS," *in Proceedings of IEEE Position Location and Navigation Symposium*, San Diego, pp. 170-176, 2000.

[13] Kubička M., Cela A., Moulin P., Mounier H., and Niculescu S., "Dataset for Testing and Training of Map-Matching Algorithms," *in Proceedings of IEEE Intelligent Vehicles Symposium*, Seoul, pp. 1088-1093, 2015.

[14] Li L., Quddus M., and Zhao L., "High Accuracy Tightly-Coupled Integrity Monitoring Algorithm for Map-Matching," *Transportation Research*

Part C: Emerging Technologies, vol. 36, pp. 13-26, 2013.

[15] Liu X., Liu K., Li M., and Lu F., "A ST-CRF Map-Matching Method for Low-Frequency Floating Car Data," *IEEE Transactions on Intelligent Transportation Systems*, vol. 18, no. 5, 1241-1254, 2017.

[16] Lou Y., Zhang C., Zheng Y., Xie X., Wang W., and Huang Y., "Map-Matching for Low-Sampling-Rate GPS Trajectories," *in Proceedings of 17th ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems*, Seattle, pp. 352-361, 2009.

[17] Meng Y., Chen W., Li Z., Chen Y., and Chao J., "A Simplified Map-Matching Algorithm for in-Vehicle Navigation Unit," *Geographic Information Sciences*, vol. 8, no. 1, pp. 24-30, 2002.

[18] Miler M., Todić F., and Ševrović M., "Extracting Accurate Location Information from A Highly Inaccurate Traffic Accident Dataset: A Methodology Based on A String Matching Technique," *Transportation Research Part C: Emerging Technologies*, vol. 68, pp. 185-193, 2016.

[19] Mohamed R., Aly H., and Youssef M., "Accurate and Efficient Map Matching for Challenging Environments," *in Proceedings of 22nd ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems*, Dallas, pp. 401-404, 2014.

[20] Mohamed R., Aly H., and Youssef M., "Accurate Real-Time Map Matching for Challenging Environments," *IEEE Transactions on Intelligent Transportation Systems*, vol. 18, no. 4, pp. 847-857, 2017.

[21] Mooney P. and Corcoran P., "Using OSM for LBS-an Analysis of Changes to Attributes of Spatial Objects," *in Proceedings of Advances in Location-Based Services*, Berlin, pp. 165-179, 2012.

[22] Naumann S. and Kovalyov M., "Pedestrian route Search Based on Open Street Map," *in Proceedings of Intelligent Transport Systems and Travel Behaviour*, Katowice, pp. 87-96 2017.

[23] Newson P. and Krumm J., "Hidden Markov Map Matching Through Noise and Sparseness," *in Proceedings of 17th ACM SIGSPATIAL International Conference on Advances in Geographic Information Systems*, Seattle, pp. 336-343, 2009.

[24] Quddus M., Ochieng W., and Noland R., "Current Map-Matching Algorithms for Transport Applications: State-of-The Art and Future Research Directions," *Transportation Research Part C: Emerging Technologies*, vol. 15, no. 5, pp. 312-328, 2017.

[25] Shalaby M., Mohammed A., and Kassem S., "Supervised Fuzzy C-Means Techniques to Solve the Capacitated Vehicle Routing Problem," *The International Arab Journal of Information Technology*, vol. 18, no. 3A, pp. 452-463, 2021.

[26] Singh S. and Singh J., *Fog, Edge, and Pervasive Computing in Intelligent IoT Driven Applications*, Wiley-IEEE Press, 2020.

[27] Singh S., Singh J., and Sehra S., "Genetic-Inspired Map Matching Algorithm for Real-Time GPS Trajectories," *Arabian Journal for Science and Engineering*, vol. 45, pp. 2587-2603, 2020.

[28] Ta N., Wang J., and Li G., "Map Matching Algorithms: An Experimental Evaluation," *in Proceedings of Asia-Pacific Web (APWeb) and Web-Age Information Management (WAIM) Joint International Conference on Web and Big Data*, Macau, pp. 182-198, 2018.

[29] Taguchi S., Koide S., and Yoshimura T., "Online Map Matching with Route Prediction," *IEEE Transactions on Intelligent Transportation Systems*, vol. 20, no. 1, pp. 338-347, 2018.

[30] Velaga N., Quddus M., and Bristow A., "Developing an Enhanced Weight-Based Topological Map-Matching Algorithm for Intelligent Transport Systems," *Transportation Research Part C: Emerging Technologies*, vol. 17, no. 6, pp. 672-683, 2009.

[31] Xu H., Liu H., Tan C., and Bao Y., "Development and Application of an Enhanced Kalman Filter and Global Positioning System Error-Correction Approach for Improved Map-Matching," *Journal of Intelligent Transportation Systems*, vol. 14, no. 1, pp. 27-36, 2010.

[32] Xu Z., Li Y., Rizos C., and Xu X., "Novel hybrid of LS-SVM and Kalman Filter for GPS/INS Integration," *The Journal of Navigation*, vol. 63, no. 2, pp. 289-299, 2010.

[33] Yang C. and Gidofalvi G., "Fast Map Matching: an Algorithm Integrating Hidden Markov Model with Precomputation," *International Journal of Geographical Information Science*, vol. 32, no. 3, pp. 547-570, 2018.

[34] Yang H., Cheng S., Jiang H., and An S., "An Enhanced Weight-Based Topological Map Matching Algorithm for Intricate Urban Road Network," *Procedia-Social and Behavioral Sciences*, vol. 96, pp. 1670-1678, 2013.

[35] Yue Y., Zhao C., Wen M., Wu Z., and Wang D., "Collaborative Semantic Perception and Relative Localization Based on Map Matching," *in Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems*, Las Vegas, pp. 6188-6193, 2020.

[36] Zeng Z., Zhang T., Li Q., Wu Z., Zou H., and Gao C., "Curvedness Feature Constrained Map Matching for Low-Frequency Probe Vehicle

Data," *International Journal of Geographical Information Science*, vol. 30, no. 4, pp. 660-690, 2016.

[37] Zhang H., Luo Y., Yu Q., Zheng X., and Li X., "Map-Matching Approach Based on Link Factor and Hidden Markov Model," *Journal of Intelligent and Fuzzy Systems Preprint*, vol. 40, no. 3, pp. 5455-5471, 2021.

[38] Zhang Y. and Sui X., "RCIVMM: A Route Choice-based Interactive Voting Map Matching Approach for Complex Urban Road Networks," *IEEE Transactions on Big Data*, vol. 1, 2021.

[39] Zhang, D., Dong Y., and Guo Z., "A Turning Point-Based Offline Map Matching Algorithm for Urban Road Networks," *Information Sciences*, vol. 565, pp. 32-45, 2021.

[40] Zhao X., Cheng X., Zhou J., Xu Z., Dey N., Ashour A., and Satapathy S., "Advanced Topological Map Matching Algorithm Based on D-S Theory," *Arabian Journal for Science and Engineering*, vol. 43, no. 8, pp. 3863-3874, 2018.

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