Review of algorithms for monitoring urban traffic in smart cities

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Abstract

Urban traffic, as a complex socio technical system, is one of the most challenging issues for monitoring in urban environments. It becomes one of the main concerns in smart cities. Recently, urban traffic monitoring attracted both researchers from academia and practitioners from variety of technical and social sciences. Although several specific solutions have been proposed and implemented in the practice, there is a need to provide comprehensive literature reviews to reveal recent publishing trends, areas of research, and point out possible further research directions. This paper presents a literature review of algorithms for monitoring urban traffic in smart cities, based on the recommendations for conducting systematic literature reviews. The objectives of the presented literature review are to inquire which types of algorithms are used for monitoring urban traffic, and which segments of urban traffic are monitored. Results of the presented review contribute to the general knowledge base on urban traffic and can be used as starting point for further review studies on specific algorithms or areas in urban traffic. In addition, presented results can serve as a starting point in finding possible solutions to specific problems in practice.

Keywords*: Smart city, Urban traffic, Monitoring algorithms*

1 Introduction

Increased number of studies dealing with traffic monitoring in urban environments cause publishing of literature reviews about some specific aspects, such as classification of vehicles by using intelligent monitoring systems [1], vision-based monitoring of road intersections [2], urban traffic monitoring by using Unmanned Aerial Vehicles (UAVs) [3], urban traffic congestion monitoring [4], and shortest path algorithms for monitoring and management urban traffic [5].

Based on inquiring existing literature and own research experience, one of the problems in smart cities is the creation of noise caused by traffic on city roads, because such roads pass through urban settlements, near hospitals, schools, and cultural monuments [6]. Studies on road traffic monitoring and eliminating traffic noise using Dijsktra and Floyd-Warshall algorithms for monitoring and navigating traffic in smart cities have recently attracted attention and popularity [7]. Important challenge in smart cities is also air pollution in road traffic in urban areas [8].

Many published papers deal with real-time parking monitoring solutions and detecting irregularities when parking vehicles using UAVs or drones. In smart cities, drones are used for the purpose of remote image collection during flight. One of the roles of drones is to detect irregularities in vehicle parking, manage parking spaces and impose penalties in case of parking violations [9]. Parking monitoring systems are based on real-time visual information.

One of the mostly researched segments of urban traffic relates to congestions. The literature

review for urban traffic congestion monitoring presents smart route planning systems and navigation systems to avoid traffic jams in smart cities. Deshmukh et al. [11] suggested alternative routes that avoid traffic jams using devices built into cars. The system enables smart route planning and navigation systems to avoid traffic jams in smart cities by suggesting to drivers the shortest way to travel to save time and fuel.

Terroso-Sáenz et al. [11] proposed an architecture for the use of external data sources to detect traffic jams. The architecture is suitable for distributed traffic information systems and uses complex event processing technology to detect congestion on the highway. Xu et al. [12] proposed two methods for estimating bus travel time using the average T-window and the average N-window, as well as the congestion indicator. Estimation methods do not support vehicles moving in spare lanes.

Bauza et al. [13] presented a traffic congestion detection technique based on communication between vehicles and fuzzy logic. The technique does not involve the use of sensors to detect traffic congestion. Leontiadis et al. [14] in their paper proposed a way to collect data on traffic jams and redirect vehicles accordingly.

The shortest path algorithms are used to monitor and manage traffic to guide the driver along the shortest route to the final destination, which results in a reduction in the total cost of setting up traffic networks [5]. The shortest path is represented by using graph theory.

There are several types of shortest path algorithms [15]: Dijkstra algorithm, Floyd-Warshall algorithm, Bellman-Ford algorithm, and Genetic algorithm. One of the most well-known algorithms for shorter paths is the Dijkstra algorithm, which has proven to be reliable in solving the problem of single-source graphs, directed and non-directed graphs [16]. Dijkstra algorithm in some cases of traffic congestion, do not suggest the shortest path.

Based on the previous considerations, the main objective of this paper is to review use of algorithms for monitoring urban traffic in smart cities. The second section presents our review methodology and results, while the third one contains discussions of results, constraints, and benefits. Concluding remarks and future research directions are presented in the last section.

2 Review methodology

The review study was designed based on guidelines for systematic literature reviews [17][18], but with appropriate simplifications as the study is a preliminary review. These simplifications are reflected in planning and conducting phase of the study in which some activities are simplified or excluded (e.g., judging the quality of the primary studies).

Design of the literature review study is presented in Figure 1. Three main phases of the presented literature review are:

- *Planning*. It includes activities necessary for planning all further activities. The most important steps are determining research questions, identification of the search keywords, identification of digital libraries in which the search will be conducted, as well as proposal of inclusion/exclusion criteria for studies.
- *Conducting*. This is the main phase in review. The activities are planned in the first phase of the study (planning). It includes searching for primary studies, appliance of inclusion/exclusion criteria, identification of primary studies and aggregation of findings based on the proposed research questions.
- *Reporting*. This is the last phase in which all relevant details of the study are reported.

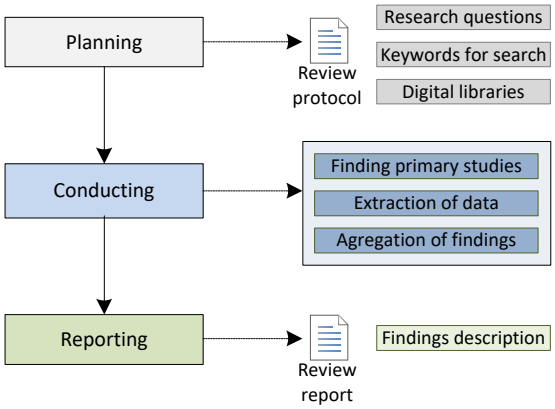

Fig. 1. Design of the literature review study

2.1 Planning

The research question proposed for this review are based on the main objective of this paper to review algorithms for monitoring urban traffic in smart cities. The following research questions are determined:

RQ1: *Which types of algorithms are used for monitoring urban traffic?*

RQ2: *Which segments of urban traffic are monitored?*

Based on the proposed research questions the following keywords for search are proposed: "urban traffic" and "monitoring algorithms". For the search are used Google Scholar and IEEE Xplore digital library because majority of the identified search result are listed in IEEE Xplore. Composed search string is:

"urban traffic" AND *"monitoring algorithms"*

Inclusion criteria for the selection of the studies used for further detailed analysis are: the study presents monitoring algorithm for urban traffic environment, the study is written in English language, the study is published in refereed journal or international conference or it is master or PhD thesis. Studies written in other languages are excluded, as well as studies for which full text is not available.

2.2 Conducting

The search for studies was performed on Google Scholar and IEEE Xplore, and it includes the period from 2012 to 2022, which ensures that the studies selected for further analysis are up to date and present the recent development in the field of research.

All identified studies are analyzed based on the proposed research questions. The selection process included analysis abstract, keywords, and introduction section of the collected papers. In some cases, when it was necessary, the whole papers were analyzed. After the analysis and implementation of the inclusion/exclusion criteria, 15 relevant studies are selected and presented in Table 1. In Table 1 are also listed used algorithms and segments of urban traffic. These studies are called Primary Studies (PS).

2.3 Reporting

In this subsection findings of the detailed literature review are presented. The findings are organized based on the proposed research questions.

RQ1: *Which types of algorithms are used for monitoring urban traffic?*

Different types of algorithms are used for monitoring traffic in urban environments. In some cases, the authors called them algorithms, methods, approaches, or procedures, which is the subject for another research. The following types of algorithms are used for monitoring: (1) multi-UAVs traffic monitoring with computation offloading/sharing policy [PS01], (2) map-based monitoring and management of object movement [PS02], (3) computer vision [PS04][PS11], (4) inertial reference data based algorithm for trajectory reconstruction and estimation and event detection [PS05], (5) neural network [PS03], (6) digraphs based recovery methods to estimate road delays and congestion [PS07], (7) Inertial Measurement Unit based estimation [PS06], (8) route planning algorithm based on spatial visualization, spatial navigation and spatial thinking [PS08], (9) algorithm based on position of magnetoresistive sensors [PS09], (10) Genetic Algorithm [PS10], (11) intelligent agents with behaviour-based model [PS12], (12) network tomography [PS13], (13) Kullback-Leibler distance (KLD) and exponential weighted moving average (EWMA) procedure [PS14], and (14) range filtering on three orthogonal planes [PS15].

Table 1. List of selected primary studies, used algorithms and segments of urban traffic

Primary Study	Reference	Algorithm	Segment of urban traffic
PS01	Alioua, A., Djeghri, H. E., Cherif, M. E. T., Senouci, S. M., & Sedjelmaci, H. (2020). UAVs for traffic monitoring: A sequential game-based computation offloading/sharing approach. Computer Networks, 177, 107273. doi: 10.1016/j.comnet.2020.107273.	monitoring with computation offloading/sharing policy	monitoring road traffic
PS02	Marchetta, P., Natale, E., Pescapé, A., Salvi, A., & Santini, S. (2015). A map-based platform for smart mobility services. In 2015 IEEE Symposium on Computers and Communication (ISCC) (pp. 19-24). Larnaca, Cyprus. doi: 10.1109/ISCC.2015.7405448.	map-based monitoring and management of object movement	smart parking services, public and private transportation fleets

			management, road traffic conditions estimation, and warnings management
PS03	Huang, Y.-Q., Zheng, J.-C., Sun, S.-D., Yang, C.-F., & Liu, J. (2020). Optimized YOLOv3 Algorithm and Its Application in Traffic Flow Detections. Applied Sciences, 10(9), 3079. doi: 10.3390/app10093079.	neural network	urban traffic flows in different scenarios and weather conditions
PS04	Liu, G., Shi, H., Kiani, A., Khreishah, A., Lee, J., Ansari, N., ... & Yousef, M. M. (2021). Smart Traffic Monitoring System Using Computer Vision and Edge Computing. IEEE Transactions on Intelligent Transportation Systems. doi: 10.1109/TITS.2021.3109481.	computer vision	traffic congestion detection and speed detection
PS05	Mousa, M., Abdulaal, M., Boyles, S., & Claudel, C. (2015). Wireless sensor network-based urban traffic monitoring using inertial reference data. In 2015 International Conference on Distributed Computing in Sensor Systems (pp. 206-207). Fortaleza, Brazil. doi: 10.1109/DCOSS.2015.21.	inertial reference data based algorithm	road traffic monitoring
PS06	Lei, T., Mohamed, A. A., & Claudel, C. (2018). An IMU-based traffic and road condition monitoring system. HardwareX, 4, e00045. doi: 10.1016/j.ohx.2018.e00045.	Inertial Measurement Unit based estimation	real-time traffic estimation and road condition monitoring
PS07	Qi, X., Wang, Y., Wang, Y., & Xu, L. (2014). Compressive sensing over strongly connected digraph and its application in traffic monitoring. In IEEE INFOCOM 2014-IEEE Conference on Computer Communications (pp. 1222-1230). Toronto, ON, Canada. doi: 10.1109/INFOCOM.2014.6848054.	digraphs based recovery methods	road traffic monitoring
PS08	Liu, R., Su, G., Tang, W., & Su, H. (2015). PTEMS: a novel public transportation emergency management system based on GIS. In Proceedings of the 1st ACM SIGSPATIAL International Workshop on the Use of GIS in Emergency Management (pp. 1-4). Bellevue, Washington, USA. doi: 10.1145/2835596.2835612.	route planning algorithm based on spatial visualization, spatial navigation and spatial thinking	public transportation vehicles management and improvement of the public transportation safety situation
PS09	Tang, Y. (2020). Monitoring Algorithm for Speed Information of Autonomous Vehicles Based on Magnetoresistive Sensor. Jordan Journal of Mechanical & Industrial Engineering, 14(1), 43-52.	algorithm based on position of magnetoresistive sensors	speed of autonomous vehicles
PS10	Novaes, A. G., Bez, E. T., Burin, P. J., & Aragão Jr, D. P. (2015). Dynamic milk-run OEM operations in over-congested traffic conditions. Computers & Industrial Engineering, 88, 326-340. doi: 10.1016/j.cie.2015.07.010.	Genetic Algorithm	dynamic vehicle routing procedure for a picking-up OEM service
PS11	Lira, G. R. (2015). A computer vision approach to drone-based traffic analysis of road intersections. Master thesis. Integrated Master's in Informatics and Computer Engineering. Faculty of Engineering of the University of Porto. Porto, Portugal.	computer vision	road intersections monitoring
PS12	Vallejo, D., Villanueva, F. J., Albusac, J. A., Glez-Morcillo, C., & Castro-Schez, J. J. (2014). Intelligent surveillance for understanding events in urban traffic environments. International Journal of Distributed Sensor Networks, 10(8), 723819. doi:	intelligent agents with behaviour-based model	urban traffic environments with pedestrians and vehicles

	10.1155/2014/723819.		
PS13	Zhang, R., Newman, S., Ortolani, M., & Silvestri, S. (2018). A network tomography approach for traffic monitoring in smart cities. IEEE Transactions on Intelligent Transportation Systems, 19(7), 2268-2278. doi: 10.1109/TITS.2018.2829086.	network tomography	realistic traveling times for cars over such topologies
PS14	[Zeroual2018] Zeroual, A., Harrou, F., Sun, Y., & Messai, N. (2018). Integrating model-based observer and Kullback–Leibler metric for estimating and detecting road traffic congestion. IEEE Sensors Journal, 18(20), 8605-8616. doi: 10.1109/JSEN.2018.2866678.	Kullback-Leibler distance (KLD) and exponential weighted moving average (EWMA) procedure	road traffic congestion estimation and detection
PS15	Tao, H., & Lu, X. (2018). Smoky vehicle detection based on range filtering on three orthogonal planes and motion orientation histogram. IEEE Access, 6, 57180-57190. doi: 10.1109/ACCESS.2018.2873757.	range filtering on three orthogonal planes	Smoky Vehicle Detection

RQ2: *Which segments of urban traffic are monitored?*

Variety of urban traffic segments were investigated in primary studies. Majority of studies implement different types of algorithms for monitoring road traffic [PS01][PS02][PS03][PS05][PS06][PS07]. Other segments of urban traffic in which monitoring algorithms were applied are: (1) smart parking [PS02], (2) transportation fleets management [PS02], (3) warnings management [PS02], (4) traffic congestion management [PS04][PS14], (5) public transportation [PS08], (6) autonomous vehicles [PS09], (7) vehicle routing [PS10][PS13], (8) road intersection monitoring [PS11], (9) movement of pedestrians and vehicles [PS12], and (10) detection of smoky vehicles [PS15]. Detailed insight int the selected primary studies revealed that road traffic monitoring is the most challenging and the most researched segment because some studies classified into other specific segments (e.g., traffic congestion management or vehicle routing) also target specific aspect of road traffic management.

3 Discussion

Presented findings in the previous section indicate that different types of algorithms, based on variety of computing and visualization techniques, are used for monitoring different segments of urban traffic. However, majority of studies are focused on specific aspects of urban road traffic monitoring.

Although presented review lists variety of monitoring algorithms, there is a need for conducting a more comprehensive and detailed review of studies based on which a more detailed systematization or taxonomy of used algorithms can be produced. This is treated as a limitation of this study conducted as a preliminary literature review. This limitation will be addressed in further research.

Despite the stated constraint related to the scope and depth of the review, there are some benefits of it. The first is the presentation of a review methodology that can be used for small scale review studies to get quick preliminary results and ideas for further research. The second is initial review of algorithms that can be considered in designing empirical studies related to traffic management.

4 Conclusion

Monitoring of traffic in urban environments is challenge for both research and practical studies because of increased population and detection of variety of problems in urban environments. This study provides a preliminary review of algorithms that can be used for monitoring traffic in urban environments, as well as a review of possible segments in which algorithms can be applied.

Further research will be directed in many directions. The first one is more detailed and systematic literature review aimed at creating systematization or taxonomy of monitoring algorithms. This review will also include search in other scientific databases and libraries such as Scopus, ScienceDirect, Wiley, and Springer.

The next extension of the research can include inquiry of other interesting aspects of monitoring urban traffic, such as review of used technologies, review of used architecture styles in proposed monitoring systems, and review of consequences of implementing monitoring systems. In addition, development of specific algorithms and systems for monitoring specific segments of urban traffic (e.g., identification of congested areas in the city using a fleet of drones) is promising research direction.

References

[1] M. Won, "Intelligent traffic monitoring systems for vehicle classification: A survey," *IEEE Access*, vol. 8, pp. 73340-73358. 2020.

[2] S.R.E. Datondji, Y. Dupuis, P. Subirats, and P. Vasseur, "A survey of vision-based traffic monitoring of road intersections," *IEEE transactions on intelligent transportation systems*, vol. 17, no. 10, pp. 2681-2698. 2016. doi: 10.1109/TITS.2016.2530146.

[3] E.V. Butilă and R.G. Boboc, "Urban Traffic Monitoring and Analysis Using Unmanned Aerial Vehicles (UAVs): A Systematic Literature Review," *Remote Sensing*, vol. 14, no. 3, pp. 620. 2022. doi: 10.3390/rs14030620.

[4] R. Baweja, R. Gupta, and N. K. Bhagat, "Improved congestion avoidance and resource allocation algorithm," in *Proceedings of 2014 2nd International Conference on Emerging Technology Trends in Electronics, Communication and Networking*, 2015, pp. 1–5. doi: 10.1109/ET2ECN.2014.7044991.

[5] S. Risald and E. Antonio, "Best Routes Section Using Dijkstra and Floyd-Warshall Algorithm," in *Proceedings of 2017 International Conference on Information & Communication Technology and System (ICTS)*, 2017, pp. 155–158.

[6] D. Dobrilović, V. Brtka, G. Jotanović, Z. Stojanov, G. Jauševac, and M. Malić, "Architecture of IoT system for smart monitoring and management of traffic noise," In *Proceedings of the 5th EAI International Conference on Management of Manufacturing Systems (EAI MMS 2020)*, 2020, pp. 251-266. doi: 10.1007/978-3-030-67241-6_21.

[7] D. Dobrilović, V. Brtka, G. Jotanović, Z. Stojanov, G. Jauševac, and M. Malić, "The urban traffic noise monitoring system based on LoRaWAN technology," *Wireless Networks*. no. 1, 2022. doi: 10.1007/s11276-021-02586-2.

[8] G. Jotanovic, J. Stojanov, D. Perakovic, Z. Stojanov, G. Jausevac and M. Stojicic, "Internet of Things Technology Purposeful for Monitoring Road Traffic Air Pollution," In *Proceedings of the 10th International conference on Applied Internet and Information Technologies (AIIT2020)*, Zrenjanin, Serbia, 2020, pp. 53-57.

[9] G. Jausevac, D. Dobrilovic, V. Brtka, G. Jotanovic, D. Perakovic, and Z. Stojanov, "Smart UAV Monitoring System for Parking Supervision," In *International Conference on Future Access Enablers of Ubiquitous and Intelligent Infrastructures (5th EAI International Conference, FABULOUS 2021)*, pp. 240-253. Springer, Cham. doi: 10.1007/978-3-030-78459-1_18.

[10] S. M. Deshmukh and B. N. Savant, "Designing an optimized smart device in vehicle for detection and avoidance of traffic congestion," in *Proceedings of 2016 Conference on Advances in Signal Processing (CASP)*, 2016, pp. 33–36.

[11] F. Terroso-Sáenz, M. Valdés-Vela, C. Sotomayor-Martínez, R. Toledo-Moreo, and A. F. Gómez-Skarmeta, "A cooperative approach to traffic congestion detection with Complex Event processing and VANET," *IEEE Transactions on Intelligent Transportation Systems*, vol. 13, no. 2, 2012, pp. 914–929. doi: 10.1109/TITS.2012.2186127.

[12] Y. Xu, Y. Wu, J. Xu, and L. Sun, "Efficient detection scheme for urban traffic congestion using buses," in *Proceedings of 2012 26th International Conference on Advanced Information Networking and Applications Workshops*, 2012. pp. 287–293. doi: 10.1109/WAINA.2012.62.

[13] R. Bauza, J. Gozalvez and J. Sanchez-Soriano, "Road traffic congestion detection through cooperative Vehicle-to-Vehicle communications," in *Proceedings of IEEE Local Computer Network Conference*, 2010, pp. 606–612. doi: 10.1109/LCN.2010.5735780.

[14] I. Leontiadis, G. Marfia, D. MacK, G. Pau, C. Mascolo, and M. Gerla, "On the effectiveness of an opportunistic traffic management system for vehicular networks," *IEEE Transactions on Intelligent Transportation Systems*, vol. 12, no. 4, 2011, pp. 1537-1548. doi: 10.1109/TITS.2011.2161469.

[15] K. Magzhan and H. Jani, "A Review and Evaluations of Shortest Path Algorithms," *International Journal of Scientific & Technology Research*, vol. 2, no. 6, 2013, pp. 99–104.

[16] I. Chahbi, D. Ben Amara, and A. Belghith, "A Novel Route Guidance Algorithm Using Beamforming Techniques for Vehicular Networks," in *Proceedings of 38th Annual IEEE Conference on Local Computer Networks - Workshops*, 2013, pp. 168–174. doi: 10.1109/LCNW.2013.6758515.

[17] B. Kitchenham, *Procedure for undertaking systematic reviews*. Computer Science Department, Keele University (TRISE-0401) and National ICT Australia Ltd (0400011T. 1), Joint Technical Report.

[18] B. Kitchenham, O.P. Brereton, D. Budgen, M. Turner, J. Bailey, and S. Linkman, ”Systematic literature reviews in software engineering–a systematic literature review,” *Information and software technology*, vol. 51, no 1, 2009, pp. 7-15. doi: 10.1016/j.infsof.2008.09.009.