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ANALYTICAL ANALYSIS OF APPROACHES TO REMOTE VEHICLES MONITORING AND DIAGNOSTICS OF DURING THEIR OPERATION

This study presents a comprehensive bibliometric analysis of the Web of Science Core Collection database to explore the current state, trends, and research needs in the field of remote vehicle monitoring and diagnostics within the automotive industry. Our objective was to identify key areas of scientific focus and emerging technological priorities by systematically examining the literature. To achieve this, we developed a complex search query using four groups of keywords. The first group targeted general automotive and diagnostic terminology, including "Diagnostic Trouble Code," "Electronic Control Unit," "On-Board Diagnostics," "transportation system," "automotive," "vehicle," "car," "vehicle diagnostic," and "vehicle monitoring." The second group covered scientific and technical approaches such as "method," "research," "diagnostics," "monitoring," "observation," "analysis," "maintenance," and "telematics." The third group focused on specific components and parameters related to vehicle performance and health, including "error," "fault," "ignition," "engine," "onboard," "OBD," "health," "performance," "driving," "habit," "fuel," "transmission," "powertrain," "ECU," "tire," "pressure," "sensor," "filter," "HVAC," and "air conditioning." The final group focused on the concept of remoteness, featuring the keyword "remote." The search results were analyzed and visualized across various dimensions, including the number of publications by year, publication types, research categories, leading authors, affiliated institutions, geographic distribution by country, research areas, and alignment with the UN Sustainable Development Goals. Furthermore, we generated a citation report and conducted an in-depth analysis of influential publications by other researchers in this domain. The results provide insights into the scientific landscape and inform future research directions for advancing remote diagnostics in intelligent transportation systems.

Keywords: vehicle, remote diagnostics, technical condition, OBD2, Diagnostic Trouble Code.

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АНАЛІТИЧНИЙ АНАЛІЗ ПІДХОДІВ ДО ВІДДАЛЕНОГО МОНІТОРИНГУ ТА ДІАГНОСТИКИ ТРАНСПОРТНИХ ЗАСОБІВ В ПРОЦЕСІ ЇХ ЕКСПЛУАТАЦІЇ

Ця стаття є аналізом бази даних Web of Science Core Collection з метою кращого розуміння перспектив автомобільної промисловості та потреб у дистанційному моніторингу та діагностиці транспортних засобів. Створено релевантний пошуковий запит, використовуючи згруповані ключові слова. Перша група: діагностичні коди несправності, електронний блок керування, бортова діагностика, транспортна система, автомобільна система, транспортний засіб, автомобіль, діагностика транспортних засобів, моніторинг транспортних засобів. Друга група: метод, дослідження, діагностика, моніторинг, спостереження, аналіз, технічне обслуговування, телематика. Третя група: помилка, несправність, запалювання, двигун, бортовий, OBD, стан, продуктивність, водіння, звичка, паливо, трансмісія, силовий агрегат, ECU, шина, тиск, датчик, фільтр, вентиляція та кондиціонування повітря, кондиціонер. Четверта група: дистанційне керування. Результати представлені у вигляді графічних ілюстрацій за кількістю публікацій, роком публікації, типом публікації, типом категорії, автором, за установою, кафедрою, країною, галуззю дослідження та ціллю сталого розвитку. Згенеровано аналітичний звіт про цитування та проведено деталізований аналіз робіт інших дослідників у цій галузі.

Ключові слова: транспортний засіб, віддалена діагностика, технічний стан, OBD2, діагностичні коди несправностей.

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INTRODUCTION

Today, the market of the automotive industry is constantly developing and growing. This leads to the growing need for efficient remote monitoring and diagnostics systems. These systems play a crucial role in ensuring vehicle reliability, safety and reducing operational costs. The integration of vehicle sensors and telematics in combination with machine learning has enabled continuous assessment of vehicle health, allowing for predictive and preventive maintenance. This study aims to evaluate the relevance and development trends of vehicle remote diagnostics and monitoring by analyzing publications indexed in the Web of Science Core Collection database.

MAIN PART

We performed analytical research to assess the research topic relevance and prospect by analyzing Web of Science Core Collection scientific database. Search terms for the query were chosen based on the relevance to a research topic. All statistical data in this paper is based on the search query - (TS=("Diagnostic Trouble Code") OR TS=("Electronic control unit") OR TS=("On-Board Diagnostics") OR TS=("transportation system") OR (TS=("automotive") AND (TS=("vehicle") OR TS=("car"))) OR TS=("vehicle diagnostic") OR TS=("vehicle monitoring")) AND (TS=("method") OR TS=("research") OR TS=("diagnostics") OR TS=("monitoring") OR TS=("observation") OR TS=("analysis") OR TS=("maintenance") OR TS=("telematics")) AND (TS=("error") OR TS=("fault") OR TS=("ignition") OR TS=("engine") OR TS=("onboard") OR TS=("obd") OR TS=("health") OR TS=("performance") OR TS=("driving") OR TS=("habit") OR TS=("fuel") OR TS=("transmission") OR TS=("powertrain") OR TS=("ecu") OR TS=("tire") OR TS=("pressure") OR TS=("sensor") OR TS=("filter") OR TS=("hvac") OR TS=("air conditioning")) AND (TS=("remote")).

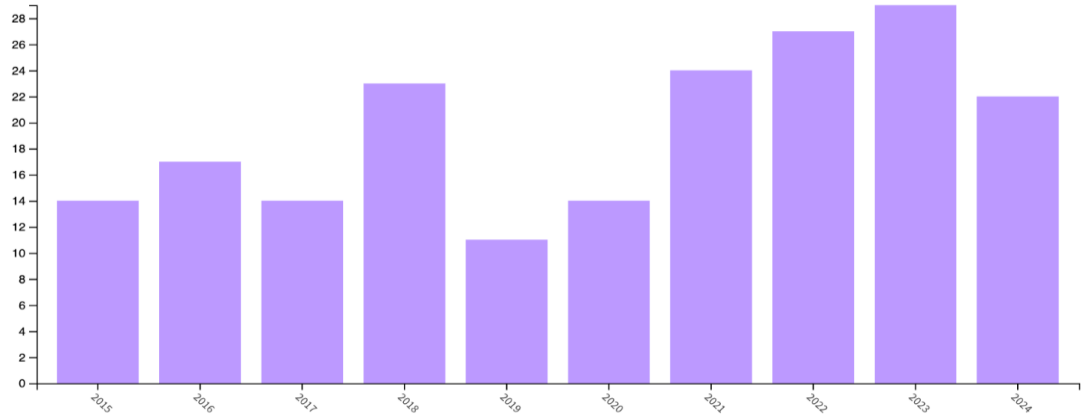

Fig. 1. Number of publications by publication year in the Web of Science Core Collection database (Publication Years)

Most researchers published their results as articles in journals – 109 or as proceeding papers – 84 (Fig. 2).

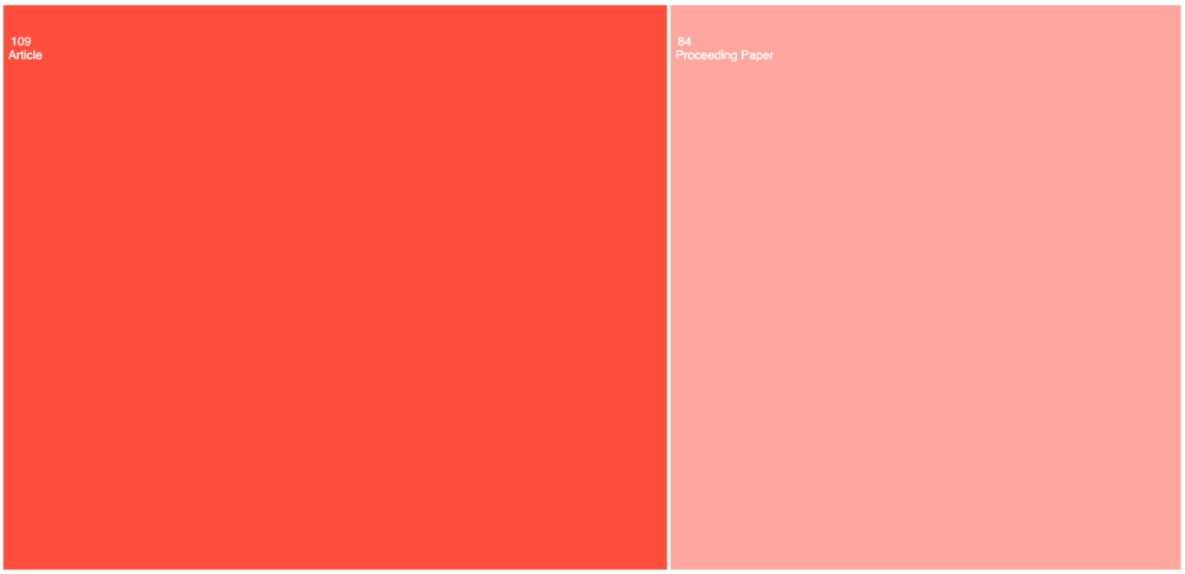

Fig. 2. Number of publications by publication type in the Web of Science Core Collection database (Document types)

The largest amount of research papers are in Engineering Electrical Electronic field – 88 and Computer Science – 59 (Computer Science Information Systems – 24, Computer Science Theory Methods – 21, Computer Science Artifical Inteligence – 14). However other categories also have a significant number of publications. Telecommunications – 39, Transportation Science Technology – 31, Instruments Instrumentation – 21, Automation Control Systems – 19, Environmental Sciences – 12, Chemistry Analytical – 11 (Fig. 3). This broad list of different categories research papers were published indicates a research topic importance in different areas of human life.

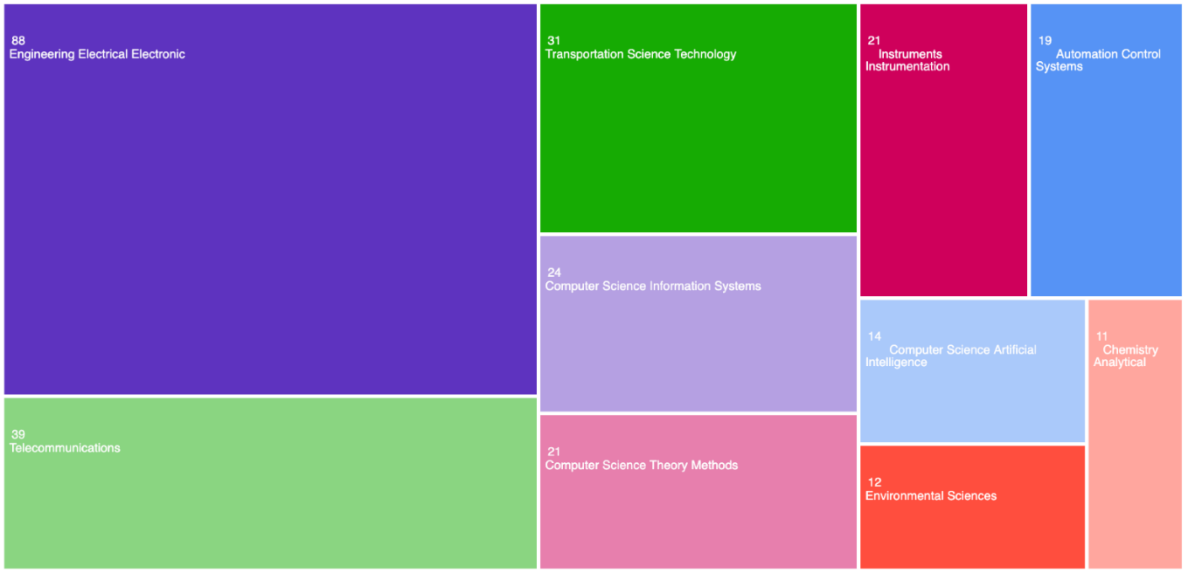

Fig. 3. Number of publications by category type in the Web of Science Core Collection database (Web of Science categories)

Most articles are published by Zhang Y – 5, Wang JF – 4, Macher G – 3, Wang XF – 3, Zhang XF – 3 (Fig. 4).

Fig. 4. Number of publications by author in the Web of Science Core Collection database (Authors) - limited to 25

Leadership among affiliations by number of publications are held by Beijing Institute Of Technology School Of Mechanical Engineering – 4, Tsinghua University School - 4 (Tsinghua University School Of Environment – 2, Tsinghua University School Of Information Science And Technology - 2), Jilin University Transportation College – 2, Polytechnic Of Milan Department Of Electronics Information And Bioengineering – 2, University Of NottinghamFaculty Of Engineering – 2, Xidian University State Key Laboratory Of Integrated Services Network – 2 (Fig. 5).

Fig. 5. Number of publications per institution department in the Web of Science Core Collection database (Affiliation with Department)

Most numbers of research papers are originating from China – 64, USA – 23, India – 19, Italy – 17, Germany – 16, England – 11, Canada – 10 (Fig. 6).

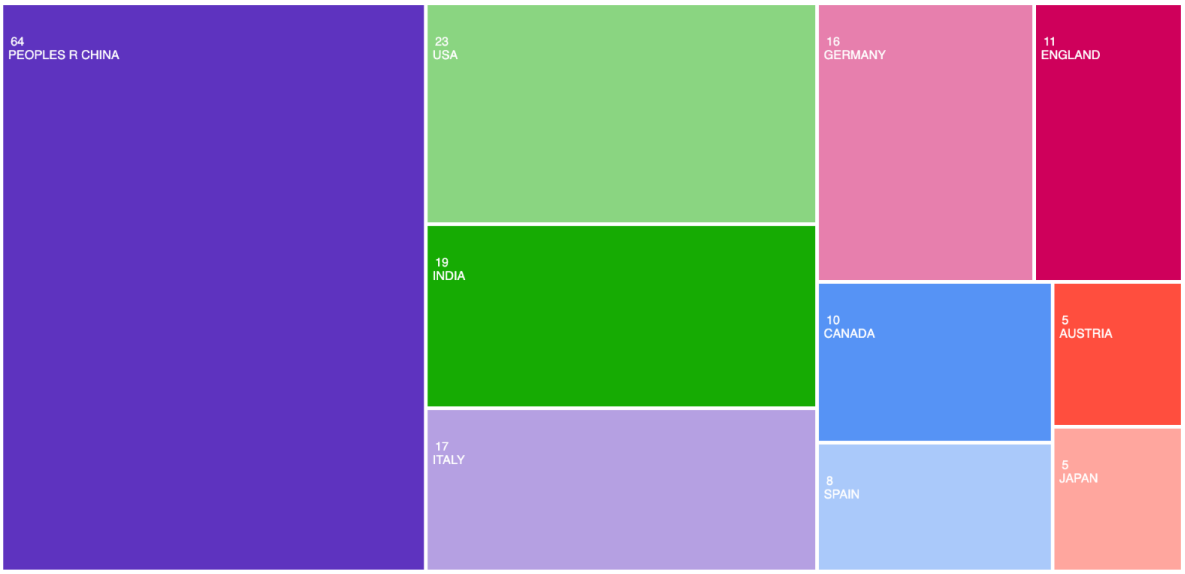

Fig. 6. Number of publications per country in the Web of Science Core Collection database (Countries/Regions)

Topic is being widely researched in various areas like Engineering – 122 publications, Computer Science – 63, Telecommunications – 39, Transportation – 32, Instruments Instrumentation – 21, Automation Control Systems – 19, Environmental Sciences Ecology – 12, Chemistry – 11, Physics – 10 (Fig. 7).

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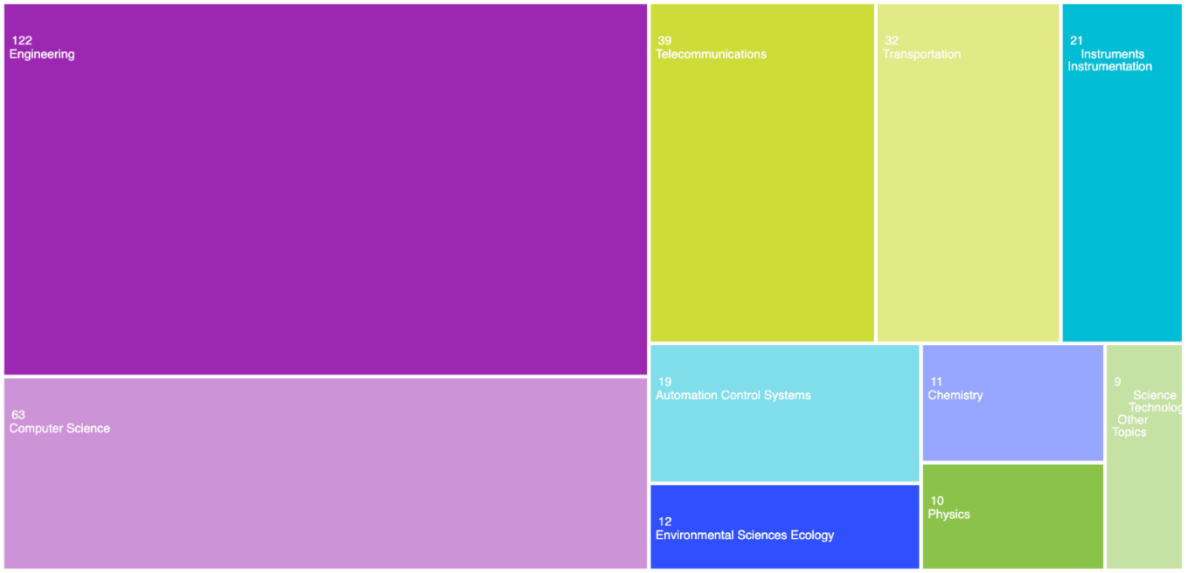

Fig. 7. Number of publications by area of research in the Web of Science Core Collection database (Research Areas)

Sustainable development is an important part of human prospect. Publications can be categorised by the sustainable development goal. Sustainable Cities And Communities takes a lead with 91 research papers, Good Health And Well Being – 43, Climate Action – 20, Affordable And Clean Energy – 12, Life On Land – 3 (Fig. 8).

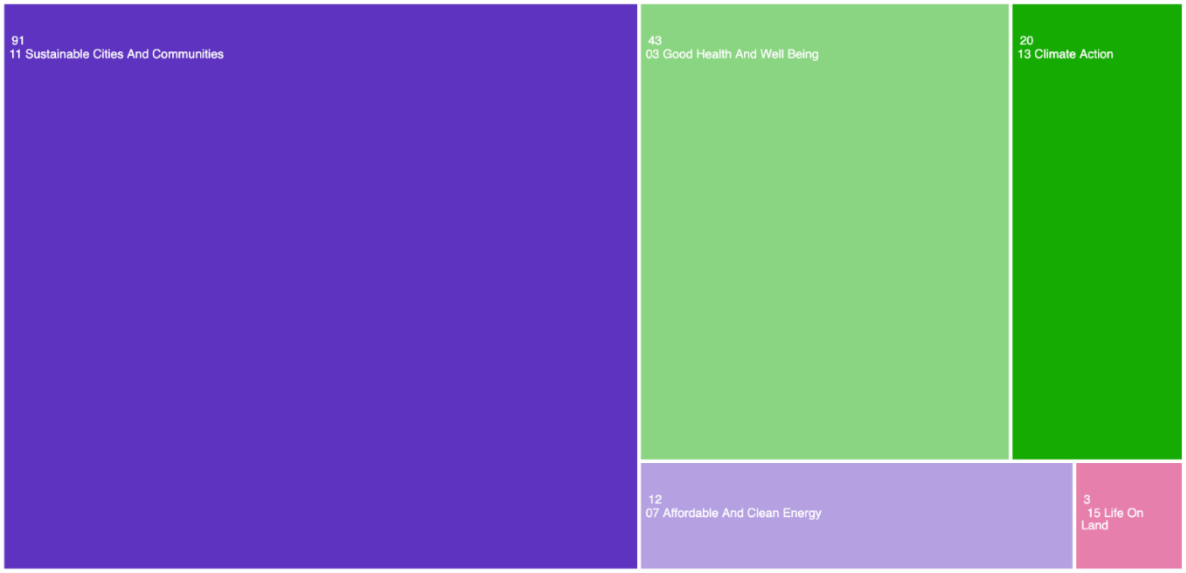

Fig. 8. Number of publications by sustainable development goal in the Web of Science Core Collection database (Sustainable Development Goal)

In order to better understand study relevance and popularity among scientists we created a citation report in the Web of Science Core Collection database. The obtained report (Fig. 9) confirms the direct correlation between published papers number and number of citations. We can see a constant growth in number of citations and published papers since 2019 peaking in 2023. Although in 2024 there is a drop in published research papers – it is still more than average number in last 10 years.

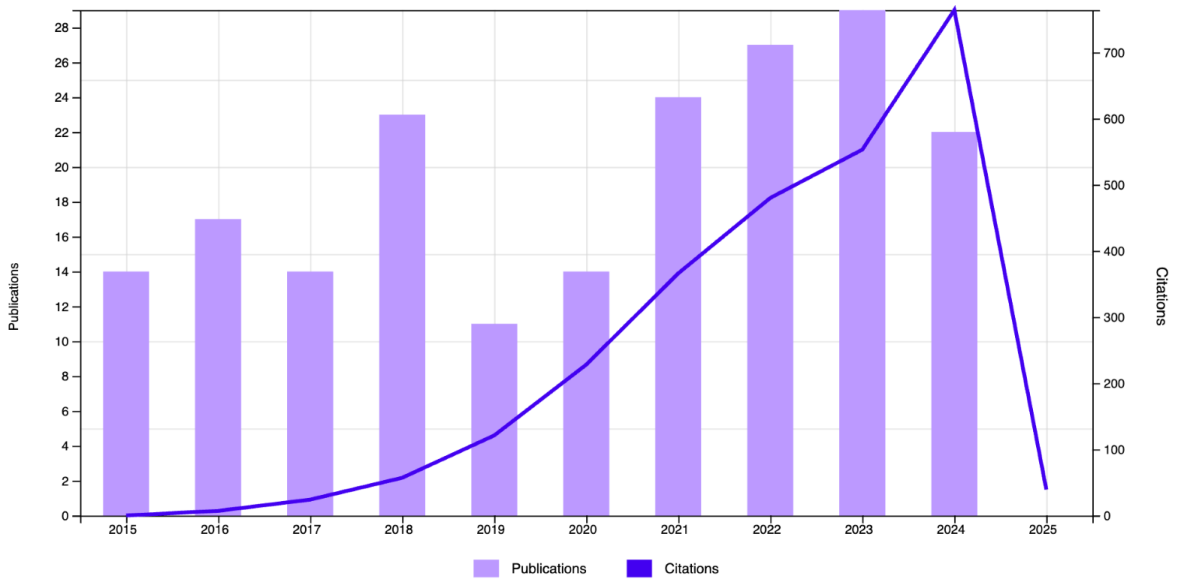

Fig. 9. Citation report in the Web of Science Core Collection database (Times Cited and Publications Over Time)

To understand scientists' interest, we analyzed the publications with the highest numbers of citations (Fig. 10, 11). Most popular cited works are: "Vehicular Edge Computing and Networking: A Survey" [1] - 350 citations, "Battery thermal management system for electric vehicle using heat pipes" [2] - 177, "Perception and sensing for autonomous vehicles under adverse weather conditions: A survey" [3] - 146, "Monitoring the effect of urban development on urban heat island based on remote sensing and geo-spatial approach in Kolkata and adjacent areas, India" [4] - 141, "Detection of Asphalt Pavement Potholes and Cracks Based on the Unmanned Aerial Vehicle Multispectral Imagery" [5] - 122, "A Review on Digital Twin Technology in Smart Grid, Transportation System and Smart City: Challenges and Future" [6] - 105, "Vehicle-Based Relay Assistance for Opportunistic Crowdsensing Over Narrowband IoT (NB-IoT)" [7] - 81, "Propagation Channels For MMWAVE Vehicular Communications: State-Of-The-Art and Future Research Directions" [8] - 68, "Remote sensing of on-road vehicle emissions: Mechanism, applications and a case study from Hong Kong" [9] - 68, "Effect of long term driving on driver discomfort and its relationship with seat fidgets and movements (SFMs)" [10] - 64.

195 Publications	Citations: highest first	1 of 4	Citations						
			‹ Previous year				Next year ›	Average per year	Total
			2021	2022	2023	2024	2025		
	Total		366	480	553	764	39	263.9	2,639
⊖ 1	Vehicular Edge Computing and Networking: A Survey Liu, L; Chen, C; (...); Zhang, Y Jun 2021 | MOBILE NETWORKS & APPLICATIONS 26 (3) , pp.1145-1168		81	100	85	57	8	58.17	349
⊖ 2	Battery thermal management system for electric vehicle using heat pipes Smith, J; Singh, R; (...); Mochizuki, M Dec 2018 | INTERNATIONAL JOURNAL OF THERMAL SCIENCES 134 , pp.517-529		38	31	36	33	2	22	176

Fig. 10. 10 most cited articles in the Web of Science Core Collection database (part 1)

3	Perception and sensing for autonomous vehicles under adverse weather conditions: A survey Zhang, YX; Carballo, A; (...); Takeda, K Feb 2023 | ISPRS JOURNAL OF PHOTOGRAMMETRY AND REMOTE SENSING 196 , pp.146-177	0	0	33	107	6	48.67	146
4	Monitoring the effect of urban development on urban heat island based on remote sensing and geo-spatial approach in Kolkata and adjacent areas, India Halder, B; Bandyopadhyay, J and Banik, P Nov 2021 | SUSTAINABLE CITIES AND SOCIETY 74	5	41	39	51	5	28.2	141
5	Detection of Asphalt Pavement Potholes and Cracks Based on the Unmanned Aerial Vehicle Multispectral Imagery Pan, YF; Zhang, XF; (...); Yang, LP Oct 2018 | IEEE JOURNAL OF SELECTED TOPICS IN APPLIED EARTH OBSERVATIONS AND REMOTE SENSING 11 (10) , pp.3701-3712	16	28	26	33	0	15.25	122
6	A Review on Digital Twin Technology in Smart Grid, Transportation System and Smart City: Challenges and Future Jafari, M; Kavousi-Fard, A; (...); Karimi, M 2023 | IEEE ACCESS 11 , pp.17471-17484	0	0	26	74	5	35	105
7	Vehicle-Based Relay Assistance for Opportunistic Crowdsensing Over Narrowband IoT (NB-IoT) Petrov, V; Samuylov, A; (...); Koucheryavy, Y Oct 2018 | IEEE INTERNET OF THINGS JOURNAL 5 (5) , pp.3710-3723	19	8	6	4	0	10.13	81
8	PROPAGATION CHANNELS FOR MMWAVE VEHICULAR COMMUNICATIONS: STATE-OF-THE-ART AND FUTURE RESEARCH DIRECTIONS Jameel, F; Wyne, S; (...); Chang, Z Feb 2019 | IEEE WIRELESS COMMUNICATIONS 26 (1) , pp.144-150	13	16	11	6	1	9.71	68
9	Remote sensing of on-road vehicle emissions: Mechanism, applications and a case study from Hong Kong Huang, YH; Organ, B; (...); Yam, YS Jun 2018 | ATMOSPHERIC ENVIRONMENT 182 , pp.58-74	11	17	5	9	0	8.5	68
10	Effect of long term driving on driver discomfort and its relationship with seat fidgets and movements (SFMs) Sammonds, GM; Fray, M and Mansfield, NJ Jan 2017 | APPLIED ERGONOMICS 58 , pp.119-127	17	10	4	4	0	7.11	64

Fig. 11. 10 most cited articles in the Web of Science Core Collection database

Analysis of the scientific works shows an increasing interest to vehicles monitoring and diagnostics. Scientists understand the importance of safe and emission-free cars to supply a sustainable future.

Today, when vehicle malfunctions, driver needs to physically drive to the repair shop and mechanic using a scanner tool can perform diagnostics on-site. This process is expensive and time consuming. The study “Possibilities of Using of Online Vehicle Diagnostics in the Future” proposes a new way of remote vehicles diagnostics [11]. They did an overview of existing approaches to preventive and predictive remote maintenance used in the aircraft industry – ACARS. The principle of this maintenance is a real-time connection between an aircraft unit and ground maintenance cabin through a satellite. The system automatically collects all relevant data from aircraft and continuously sends it through the channel to ground personnel. This allows us to prepare for any repairs in advance before the aircraft lands or correct any technical malfunction by localizing it as early as possible to prevent a chain reaction that might cause more serious issues.

Remote vehicle diagnostics' main purpose is to share data with other people or systems. This process includes data providers, data reading, data transmit, data analysis, data sharing (Fig. 12).

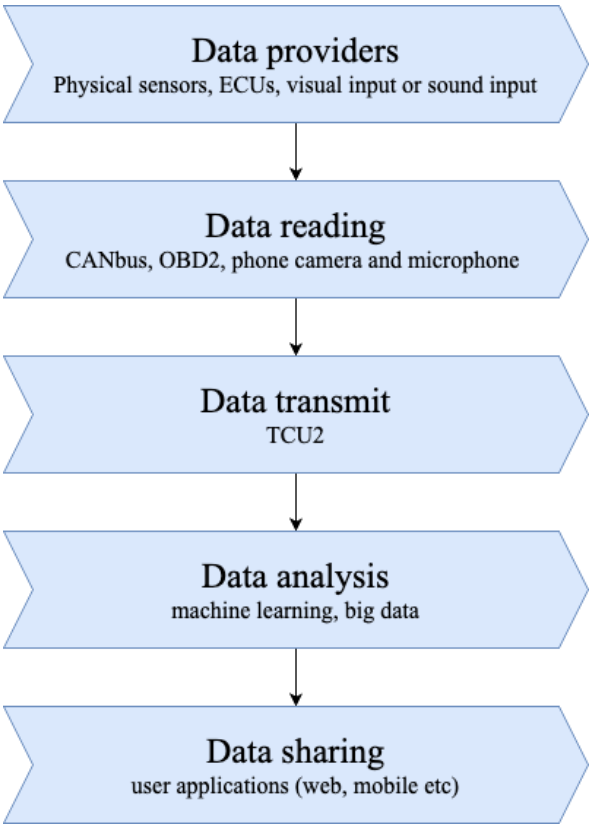

Fig. 12. Stages of remote vehicle diagnostics

Data providers are any physical components that provide particular information about vehicles like vehicle speed sensor, cabin air quality sensor, steering angle sensor etc. There are a lot of different sensors, and they are usually grouped and managed by different Electronic Control Units (ECUs). Additional data that can be used to monitor the vehicle's state can be a visual input (any visible physical damage vehicle has) or sound input (any hearable malfunction e.g. engine knocking).

Data reading is a process that focuses on obtaining data from data providers. All vehicle ECUs are connected together using a CAN (Controller Area Network) bus – a communication system that allows ECUs to directly communicate with each other. For diagnostics purposes every gasoline vehicle since 2004 all vehicles in EU must have a special port called OBD2 (On-board diagnostics) and located not more than 0.61m from the steering wheel. OBD2 utilizes CAN bus protocol and allows reading Diagnostic Trouble Codes (DTCs) and sensors data directly from ECUs. OBD2 has several protocol standards (SAE J1850 PWM, SAE J1850 VPW, ISO 9141-2, ISO 14230 KWP2000, ISO 15765 CAN) and standardized set of PIDs that are used to access specific data.

Data can be also provided by visual and sound inputs. There are cases when sensors can't detect a specific issue. In case of any physical damage to a vehicle, the driver must have the ability to share it with a mechanic or service provider. This can be achieved by providing an ability to attach an image with physical damage to a car body or an audio recording with wheezes. This type of analysis should be used as on-demand and explicitly started by driver to avoid any security concerns.

Data transmission is the most crucial component in remote vehicle monitoring and diagnostics. Technology development and spread of cellular networks encouraged embedding a real-time connectivity with cloud services into vehicles. Telematic control unit (TCU) is a component used in automotive industry that supplies vehicle with mobile communication technologies. A study "Vehicular Edge Computing and Networking: A Survey" (1) proposes a new architecture for vehicles edge communication. Vehicular Edge Computing (VEC) is expected to be a better fit for vehicles with less latency as opposed to Vehicular Ad Hoc Network (VANET) or Mobile Edge Computing (MEC) paradigms.

Data analysis is a process that is mostly done on cloud after all data is transmitted but can also take place on board if needed. This includes data processing, normalizing and running different algorithms to predict any malfunctions that can happen in future. Scientists Sandeep Nair Narayanan, Sudip Mittal, Anupam Joshi in "OBD SecureAlert: An Anomaly Detection System for Vehicles" [12] did a comprehensive experiment in finding anomalies in collected vehicle signals. Anomalies can help detect an attack on a vehicle based on abnormal data or be used to in predictive and preventive maintenance.

Data sharing is the final step in remote vehicle monitoring and diagnostics. It must provide an ability for mechanic or service provider monitor vehicle state in real-time. The tools can be different including a web site, mobile app or API (Application Programming Interface) services.

Since the OBD2 standard defines a limited set of PIDs for vehicle diagnostics, vehicle vendors extend OBD2 with proprietary PIDs. This makes each vehicle require a unique decoding approach. This lack of standardization prevents mechanics, fleet operators, and diagnostic companies from obtaining comprehensive and consistent vehicle data. The study [11] proposes a new paradigm to solve this gap. The approach involves abstraction of vehicle data by each vendor's specific backend server (Fig. 13). The purpose of this server is to bridge and map proprietary data to a new format that must be defined by a provider server. A provider server than collects all data and is accessible by the end consumers.

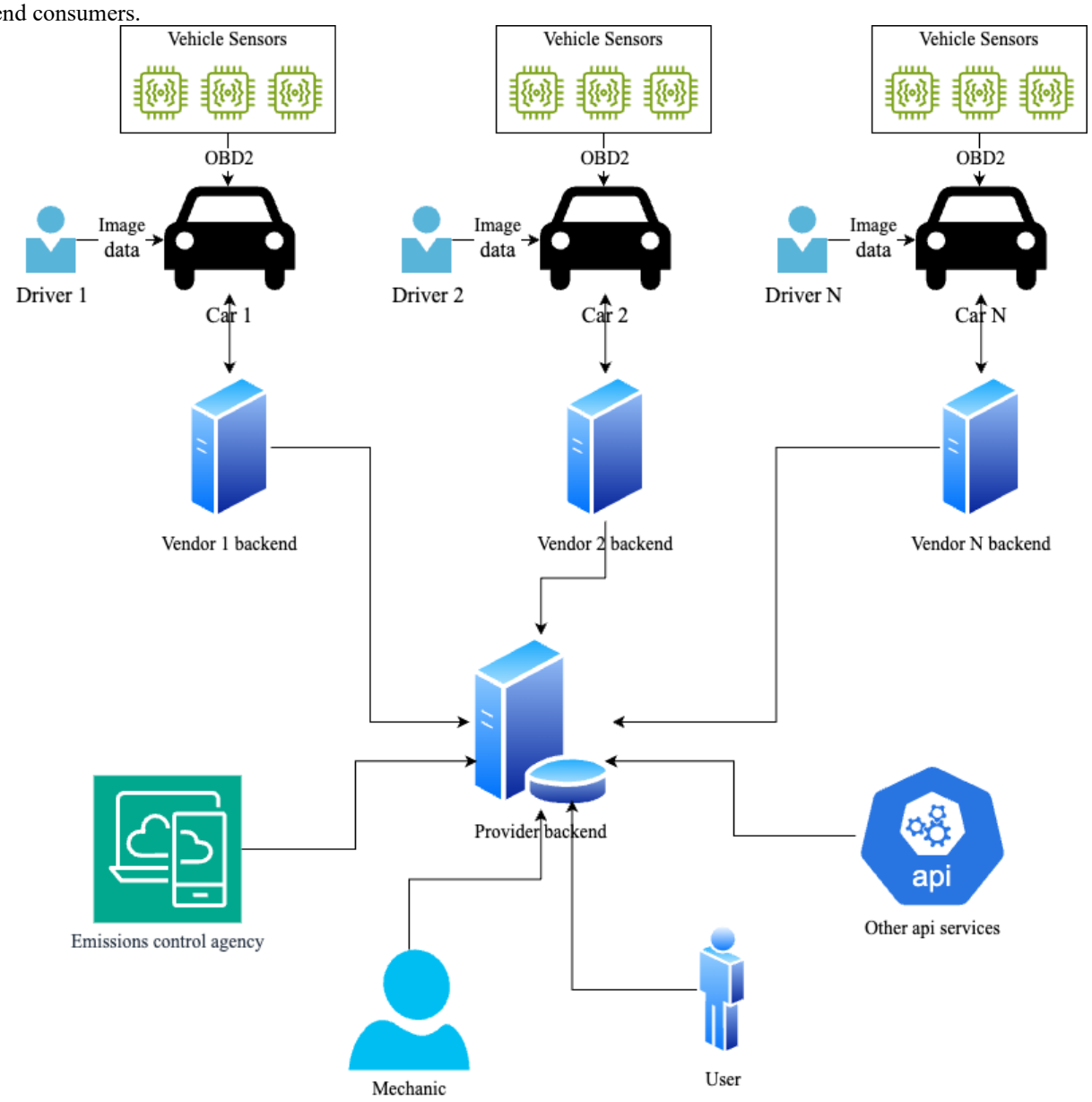

Fig. 13. A new standardized approach to remote vehicle monitoring and diagnostics

CONCLUSION

This paper provides an analytical analysis of approaches to remote vehicles monitoring and diagnostics during their operation. We used Web of Science Core Collection database and a search query specific to a topic. Query results of papers by publication year shown a steady growth since 2019. Additionally, we analyzed Search results were analyzed scientific works by number of publications by publication type, by category type, author, per institution department, per country, by area of research and by sustainable development goal. We also created a citation report and listed the 10 most cited research papers. Analysis of the existing approaches to remote vehicle monitoring and diagnostics shows a bright and perspective future in this area.

References

1. Liu, L., Chen, C., Pei, Q. et al. Vehicular Edge Computing and Networking: A Survey. Mobile Netw Appl 26, 1145–1168 (2021). https://doi.org/10.1007/s11036-020-01624-1
2. Joshua Smith, Randeep Singh, Michael Hinterberger, Masataka Mochizuki, Battery thermal management system for electric vehicle using heat pipes, International Journal of Thermal Sciences, Volume 134, 2018, Pages 517-529, ISSN 1290-0729, https://doi.org/10.1016/j.ijthermalsci.2018.08.022.
3. Yuxiao Zhang, Alexander Carballo, Hanting Yang, Kazuya Takeda, Perception and sensing for autonomous vehicles under adverse weather conditions: A survey, ISPRS Journal of Photogrammetry and Remote Sensing, Volume 196, 2023, Pages 146-177, ISSN 0924-2716, https://doi.org/10.1016/j.isprsjprs.2022.12.021.
4. Bijay Halder, Jatisankar Bandyopadhyay, Papiya Banik, Monitoring the effect of urban development on urban heat island based on remote sensing and geo-spatial approach in Kolkata and adjacent areas, India, Sustainable Cities and Society, Volume 74, 2021, 103186, ISSN 2210-6707, https://doi.org/10.1016/j.scs.2021.103186.
5. Y. Pan, X. Zhang, G. Cervone and L. Yang, "Detection of Asphalt Pavement Potholes and Cracks Based on the Unmanned Aerial Vehicle Multispectral Imagery," in IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, vol. 11, no. 10, pp. 3701-3712, Oct. 2018, doi: 10.1109/JSTARS.2018.2865528.
6. M. Jafari, A. Kavousi-Fard, T. Chen and M. Karimi, "A Review on Digital Twin Technology in Smart Grid, Transportation System and Smart City: Challenges and Future," in IEEE Access, vol. 11, pp. 17471-17484, 2023, doi: 10.1109/ACCESS.2023.3241588.
7. V. Petrov et al., "Vehicle-Based Relay Assistance for Opportunistic Crowdsensing Over Narrowband IoT (NB-IoT)," in IEEE Internet of Things Journal, vol. 5, no. 5, pp. 3710-3723, Oct. 2018, doi: 10.1109/JIOT.2017.2670363.
8. F. Jameel, S. Wyne, S. J. Nawaz and Z. Chang, "Propagation Channels for mmWave Vehicular Communications: State-of-the-art and Future Research Directions," in IEEE Wireless Communications, vol. 26, no. 1, pp. 144-150, February 2019, doi: 10.1109/MWC.2018.1800174.
9. Yuhan Huang, Bruce Organ, John L. Zhou, Nic C. Surawski, Guang Hong, Edward F.C. Chan, Yat Shing Yam, Remote sensing of on-road vehicle emissions: Mechanism, applications and a case study from Hong Kong, Atmospheric Environment, Volume 182, 2018, Pages 58-74, ISSN 1352-2310, https://doi.org/10.1016/j.atmosenv.2018.03.035.
10. George M. Sammonds, Mike Fray, Neil J. Mansfield, Effect of long term driving on driver discomfort and its relationship with seat fidgets and movements (SFMs), Applied Ergonomics, Volume 58, 2017, Pages 119-127, ISSN 0003-6870, https://doi.org/10.1016/j.apergo.2016.05.009.
11. Nagy, Jozsef & Lakatos, István. (2022). Possibilities of Using of Online Vehicle Diagnostics in the Future. 10.1007/978-3-031-15211-5_7.
12. S. N. Narayanan, S. Mittal and A. Joshi, "OBD_SecureAlert: An Anomaly Detection System for Vehicles," 2016 IEEE International Conference on Smart Computing (SMARTCOMP), St. Louis, MO, USA, 2016, pp. 1-6, doi: 10.1109/SMARTCOMP.2016.7501710.