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Review Article

Analysis of Advanced Technologies to Reduce Traffic Accidents in Foggy Conditions

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Abstract *- Fog is one of the factors that affect visibility on roads the most, contributing to 15% of road accidents worldwide, especially in mountainous and rural areas. In the central highlands, 30% of fatal accidents are related to these conditions, with an increase of 20% during critical months. This study aims to analyze advanced technologies, such as adaptive lighting systems, driver assistance devices and artificial intelligence algorithms, aimed at reducing accidents in foggy scenarios. The methodology used a systematic review under the PRISMA guidelines, using the Scopus and IEEE Xplore databases. After applying inclusion and exclusion criteria, 138 articles published between 2003 and 2024 were analyzed. Tools such as VOSviewer and Google Colab facilitated bibliometric analysis and trend visualization. The results showed that China leads the research with 67 publications, followed by the United States with 26 publications and India with 13 publications. A total of 80 scientific articles and 70 conference articles were identified, with a predominance in engineering (34.7%) and computer science (25%). The technologies analyzed, especially those based on artificial intelligence, showed improvements of 30%, 40%, and 22% in detection systems. Despite these advances, its implementation faces economic and infrastructural challenges, so it is suggested that international collaborations be promoted and solutions adapted to local contexts be developed to improve road safety.*

Keywords *- Fog, Security, Technology, Detection, Review, Traffic.*

1. Introduction

Every year, thousands of lives are lost due to road accidents in low-visibility conditions, where fog is one of the main triggers [1]. The drastic reduction in visibility caused by this weather phenomenon makes it difficult to perceive other vehicles, traffic signs and obstacles, significantly increasing the risk of collisions [2]. It is estimated that around 15% of road accidents occur under these circumstances, with an especially severe impact on mountainous and rural regions [3-4]. In countries with variable climates and complex topography, the cases are even more alarming [5]. In the central highlands, for example, 30% of fatal accidents are related to fog, and during the months of greatest incidence, a 20% increase in road accidents is reported [6]. These figures not only reflect a worrying loss of human life but also generate high economic costs associated with material damage, medical care and decreased productivity[7].

Faced with this problem, the development and implementation of advanced technologies are presented as essential solutions to reduce accidents in foggy conditions. Adaptive lighting systems, driver assistance devices and algorithms based on artificial intelligence stand out among the main technological innovations, allowing visibility to be improved and hazards to be anticipated in real time [8]. These tools not only make it easier to detect obstacles but also alert drivers and automate preventative actions to avoid collisions.

However, the implementation of these technologies faces significant challenges, especially in resource-limited regions. The lack of adequate infrastructure and restricted accessibility to these systems make it difficult to implement them on a large scale [9]. Therefore, it is essential to analyze existing technologies, evaluate their effectiveness and propose improvements adapted to the conditions of each region [10, 11].

The present study aims to examine advanced technologies aimed at reducing traffic accidents in foggy conditions, highlighting their benefits, limitations and prospects. In the research, they proposed an innovative approach to improve lane detection in foggy conditions by using synthetic data. Using a monocular depth prediction model and an atmospheric scattering model, they generated artificial fog images based on the CULane dataset. The results demonstrated a significant

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increase in detection accuracy (F1-measure) from 11.09 to 70.41 in dense fog conditions. They conclude that the proposed approach optimizes the accuracy of the model without affecting its performance in other climatic environments.

On the other hand, [12] analyzed the relationship between meteorological visibility and Traffic Safety Visual Distance (TSVD) in foggy scenarios. They measured dynamic and static visual distances for 12 drivers under different levels of visibility, comparing both capabilities. The results indicated that dynamic DORV was lower than static VAT, showing that visibility directly influences the recommended speed limits. They conclude that visibility allows safe maximum speeds to be calculated to ensure more controlled driving conditions in adverse scenarios.

In addition, they studied [13] how fog impacts the visual performance of drivers on a Brazilian road section using a driving simulator. They compared visual performance in clear and foggy conditions, showing that the tracked area decreased, pupillary dilation was lower, and the number of fixations increased in the presence of fog. The authors conclude that fog considerably affects visual perception of the environment, reducing drivers' ability to identify critical elements of the road, thus compromising road safety.

Finally, they developed [14] a feature fusion method to optimize the performance of camera sensors in obstacle detection in foggy conditions. Using a trained YOLOv3 model with fused images on sunny and cloudy days, they achieved improvements of 30% in mAP, 40% in Recall, and 22% in F1-Score. The results show that feature fusion significantly improves detection in harsh environments. They conclude that this technique optimizes the safety and efficiency of artificial vision systems in unfavorable weather conditions.

Therefore, the presence of fog represents a critical challenge for road safety by drastically reducing visibility and compromising the ability of drivers to anticipate and react to possible risks. Despite technological advances that have proven to be effective in various applications, their implementation faces barriers related to infrastructure, costs, and regional adaptability. Addressing this problem will not only save human lives but also mitigate the economic and social impacts generated by road accidents in low visibility conditions.

This study is structured as follows: Section 2 describes the methodology applied, including the criteria for selecting sources and the tools used for data analysis. Subsequently, in Section 3, the results obtained are discussed, highlighting the most relevant technological advances and their effectiveness in adverse conditions. Finally, Section 4 discusses and concludes with an analysis of the findings, the limitations of the study and recommendations for future research.

2. Materials and Methods

In this study, the hybrid PRISMA methodology in Figure 1 was applied with the purpose of conducting a systematic and comprehensive review of the scientific literature on advanced technologies to reduce traffic accidents in foggy conditions. The review was developed in four structured phases.

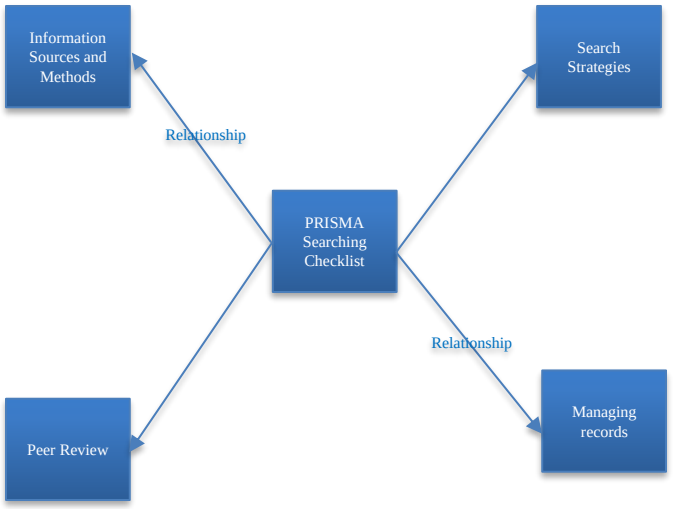

Fig. 1 Hybrid PRISMA methodology

2.1. First Phase Sources and Methods

In this phase, a systematic search and compilation of information was carried out in the Scopus database, which offers access to a wide range of indexed scientific publications [15]. Articles and conference papers published between 2013 and 2024 were selected, excluding other types of documents such as reviews, book chapters, editorials and errata [16].

The main objective of this stage was to collect studies that analyze technological solutions focused on the mitigation of accidents in foggy conditions. This included research on adaptive lighting systems, driver assistance devices, artificial intelligence algorithms, and real-time monitoring tools.

2.2. Second Phase: Search Strategy

The search strategy was based on the use of Boolean keywords and operators applied within the Scopus platform to ensure the accuracy of the results. We set specific filters to narrow down results to relevant, high-quality studies. The search included terms such as:

"fog mitigation," "driver assistance devices," "adaptive lighting systems," "low visibility," "traffic accidents," "artificial intelligence," and "road safety."

The results obtained were exported in CSV format and processed using data analysis tools such as RStudio and Google Collaboratory, facilitating the organization and evaluation of the information collected.

2.3. Phase Three Preview

During this phase, a bibliometric analysis of the selected studies was conducted to identify patterns, trends, and key areas of research. The VOSviewer tool was used to generate maps of the co-occurrence of terms [17], which allowed us to visualize the relationship between key concepts and outstanding authors in the study area.

In addition, statistical analyses were carried out using RStudio and the Pandas library in Google Colab to graph data such as the annual distribution of publications, contributions by country and most cited authors [18].

The results were presented in the form of comparative graphs and, at the end, a cluster map showing the main lines of research related to accident mitigation in foggy conditions.

To ensure the relevance and quality of the selected studies, specific inclusion and exclusion criteria were applied. The studies had to be original publications in scientific journal articles or conference papers covering the period 2003-2024. Research focused on technologies applied to accident mitigation in foggy conditions, including technological devices, artificial intelligence algorithms and driver assistance systems, was considered. Reviews, book chapters, errata, editorials, short notes, studies not related to road safety in foggy conditions, and duplicate publications or publications with incomplete information were excluded.

2.4. Fourth Phase of Registration

The information collected and processed was systematically recorded in an organized database, ensuring its accessibility and traceability for future analysis. This registry included details such as study title, authors, year of publication, country of origin, technology analyzed, and main findings.

2.5. Tools

2.5.1. To. Scopus

Scopus was the main source of information for the search and compilation of scientific studies. This database allowed access to high-quality publications, facilitating the identification of relevant studies on advanced technologies applied in foggy conditions [15].

2.5.2. IEEE Xplore

IEEE Xplore complemented the search by providing access to specific engineering research and advanced technology focused on practical solutions applied to road safety.

2.5.3. Vosviewer

Vosviewer is a software tool designed to build and visualize bibliometric networks, which can include journals, researchers, or individual publications. VOSviewer was used to analyze the relationships between authors, publications, and key concepts, generating visual maps of term co-occurrence. This tool made it possible to identify the main areas of research and the most studied technologies in the field of road safety in foggy conditions [19].

2.5.4. Google Collaborate

Google Collaboratory, or Google Colab, is a free platform offered by Google that provides a cloud-hosted Jupyter Notebook environment, allowing you to write and run Python code. Google Colab and RStudio were used for the analysis and processing of data exported from Scopus [20]. Using Python and its libraries, such as Pandas and Matplotlib, statistical and graphical analyses were performed to visualize publication trends, impact of studies, and contributions by country or author.

3. Results

The systematic search carried out in the Scopus and IEEE Xplore databases, under the defined criteria, allowed the identification of a relevant set of studies focused on advanced technologies for the mitigation of traffic accidents in foggy conditions. Scientific articles and conference papers published between 2013 and 2024 were analyzed, excluding documents not aligned with the objective of this study.

The results obtained reveal significant trends in the use of technological devices, artificial intelligence algorithms and monitoring systems that seek to improve visibility and safety in low-visibility environments.

3.1. First Phase Sources and Methods

In the first phase of the search, systematic exploration was carried out in the Scopus and IEEE Xplore databases without applying the defined inclusion and exclusion filters. Initial results reveal a progressive growth in scientific production related to technologies for accident mitigation in foggy conditions since 2003, which marks a turning point in research in this field.

This finding suggests that establishing 2003 as the starting year in the search is the most appropriate since it allows us to recover relevant studies without ignoring previous efforts in the field.

Figure 2 illustrates the temporal evolution of the documents identified in Scopus. From 1929 to the early 2000s, scientific production was scarce, with an average of less than 5 documents per year. However, since 2003, there has been a sustained increase in publications, reaching its maximum in recent years with about 30 documents in a single year. This trend confirms the growing interest of the scientific community in the development of technological solutions to meet the challenges of reduced visibility on roads.

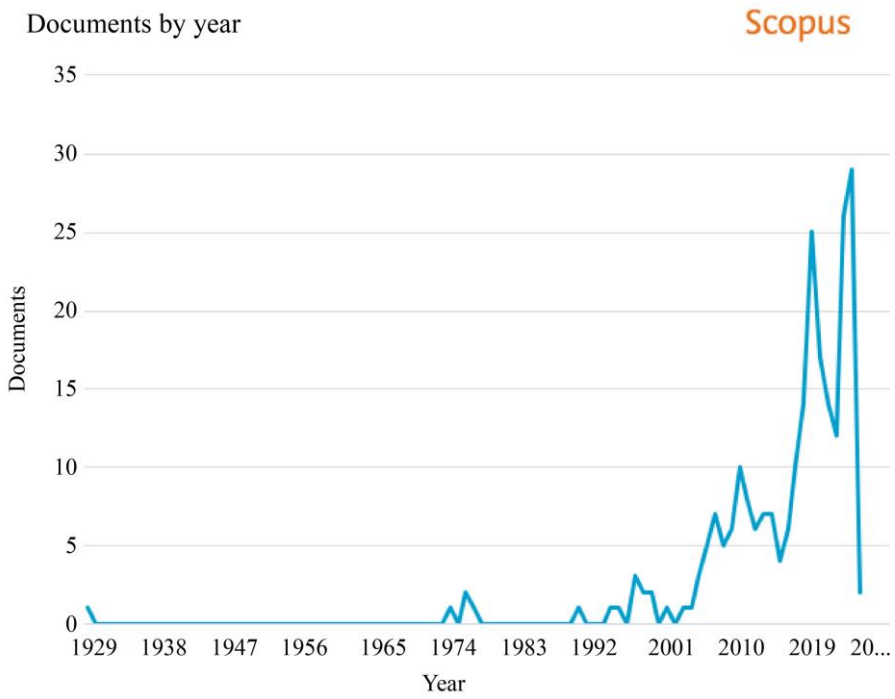

Fig. 2 Historic Documents by Year

It is important to note that this phase corresponds to the results without the application of specific filters, such as the exclusion of reviews and book chapters, which will be addressed in later stages of the analysis.

3.2. Second Phase: Search Strategy

The systematic search was carried out by applying a Boolean algorithm in the Scopus and IEEE Xplore databases, which allowed the identification of publications related to advanced technologies to mitigate accidents in foggy conditions. Combinations of terms with AND and OR operators were used, allowing the inclusion of specific and general concepts such as "fog AND traffic AND safety", "device", "algorithm", "sensor", and "network". Additionally, the truncator asterisk (*) was applied to recover keyword variations, expanding the coverage of the results obtained.

(TITLE-ABS-KEY (fog) AND TITLE-ABS-KEY (traffic AND safety) OR TITLE (device) OR TITLE (algorithm*) OR TITLE (lighting) AND TITLE-ABS-KEY (weather) OR TITLE (technology) OR TITLE (sensor) OR TITLE (ai) OR TITLE (network) AND NOT TITLE-ABS-KEY (aviation) AND NOT TITLE-ABS-KEY (maritime) AND NOT TITLE-ABS-KEY (indoor) AND NOT TITLE-ABS-KEY (training AND method) AND NOT TITLE-ABS-KEY (machine AND learning) AND NOT TITLE-ABS-KEY (neural AND networks) AND NOT TITLE-ABS-KEY (fog AND computing))

On the other hand, exclusion criteria were implemented with the NOT operator, eliminating works related to "aviation", "maritime", and "indoor", as well as research focused on neural networks or training methods, using terms such as "NOT neural AND networks" and "NOT training AND method". The application of these filters allowed the results to be refined, focusing only on studies pertinent to the field of meteorological fog and its impact on road safety.

3.3. Phase Three Preview

The tables presented correspond to results obtained from Scopus and IEEE Xplore, two scientific databases widely used for the compilation of academic and technical literature. Table 1 shows a classification of documents by type, with articles (80) and conference papers (70) predominating, followed by book chapters and other types of documents, such as reviews and retracted papers. This data reflects the importance of prioritizing literature with the greatest impact and rigour, such as peer-reviewed articles and papers presented at prestigious academic conferences. The exclusion criteria used eliminated less relevant documents, such as conference reviews, to ensure that only primary sources that bring scientific and technical value to the research are considered.

Table 1. Exclusion by document type

Document Type	Exclude	Number of Results
Article		80
Conference paper		70
Book chapter	X	3
Retracted	X	1
Review	X	1
Conference review	X	1

Table 2 details the results by thematic areas, highlighting the predominance of engineering (164 results), computer science (86) and social sciences (72). This indicates that the research collected comes from disciplines with greater scientific production on the selected platforms. The inclusion criteria focused on areas related to technology, applied science, and humanities, while the exclusion criteria eliminated less relevant or underrepresented fields, such as arts and humanities and economics, with just one result each. This process ensures that the final selection is aligned with the objectives of the research, favoring a coherent and specific approach towards the priority fields of study.

Table 2. Exclusion by subject area

Subject Area	Exclude	Number of Results
Engineering		164
Computer Science		86
Social Sciences	X	72
Physics and Astronomy		33
Mathematics		33
Medicine		29
Environmental Science		26
Materials Science		20
Earth and Planetary Sciences		15
Energy		11
Multidisciplinary		7
Biochemistry, Genetics and Molecular Biology	X	6
Psychology	X	5
Chemistry	X	5
Decision Sciences		5
Chemical Engineering	X	2
Neuroscience	X	2
Health Professions	X	2
Business, Management and Accounting	X	2
Agricultural and Biological Sciences	X	1
Economics, Econometrics and Finance	X	1
Arts and Humanities	X	1

3.4. Fourth Phase of Registration

The data obtained in BibTeX format from the Scopus and IEEE Xplore databases were processed using Biblioshiny in the RStudio environment, which allowed a detailed bibliometric analysis to be performed. Subsequently, the results were exported and graphed using Google Collaboratory, taking advantage of Python libraries such as Pandas and Matplotlib. The figures generated include the evolution of scientific production by year, the distribution of documents by thematic area and the number of publications by country or territory. These graphs offer a visual representation of the most relevant trends and contributions in the field of technologies applied to the mitigation of traffic accidents in foggy conditions.

Figure 3 shows the evolution of scientific production on advanced technologies to mitigate traffic accidents in foggy conditions, based on Scopus data during the period 2004-2024. Significant growth is evident from 2016, peaking in 2018 with 17 publications. Between 2013 and 2016, production remained stable, with an annual average of 4 documents. In 2017, there was an increase of 75% compared to the previous year, reflecting a growing interest in this topic. However, the trend declined during 2019 and 2020, followed by a further rebound in 2023 and 2024, when production reached 16 documents per year in both years.

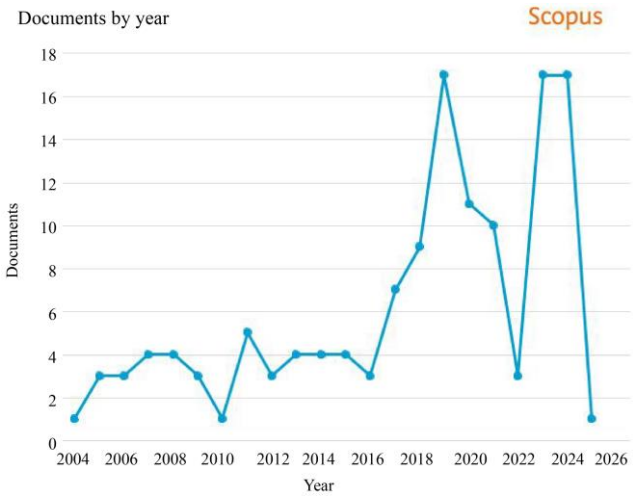

Fig. 3 Documents by Year

Figure 4 presents the distribution of documents by thematic area, showing that Engineering leads with 34.7% of the total publications, followed by Computer Science with 25.0%, which reflects a predominant focus on technological development and the implementation of systems applied to the mitigation of accidents in foggy conditions. Other outstanding areas include Mathematics with 8.9% and Physics and Astronomy with 8.1%, which suggests a contribution from scientific disciplines related to the analysis of meteorological phenomena and data.

The areas of Environmental Sciences and Earth and Planetary Sciences represent 5.1% and 4.7%, respectively, evidencing the relevance of the study of climate and its impacts on-road visibility. Finally, a lower contribution is observed from fields such as Medicine (2.1%), Energy (3.0%) and Multidisciplinary (3.0%), with 0.8% classified as others, indicating a limited interest in these specific sectors within the field analyzed.

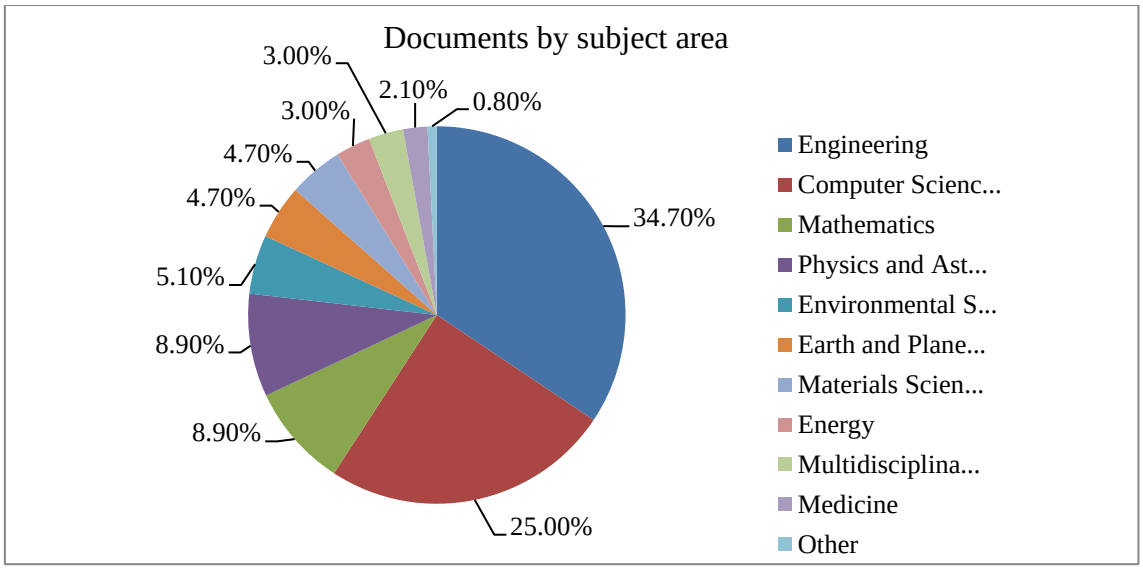

Fig. 4 Documents by subject area

Figure 5 shows the distribution of documents by country or territory, where China leads with 67 publications, representing approximately 38% of the total, followed by the United States with 26 documents (about 15%). Thirdly, India has 13 publications, while countries such as Germany and France contribute 9 and 8 documents, respectively. Other countries, such as Canada and Romania, submit between 6 and 5 publications, while South Korea and the Russian Federation contribute 4 documents each. Finally, countries such as Japan, Mexico, Spain and Indonesia register minor contributions, with 1 document evidencing reduced participation compared to the main scientific producers.

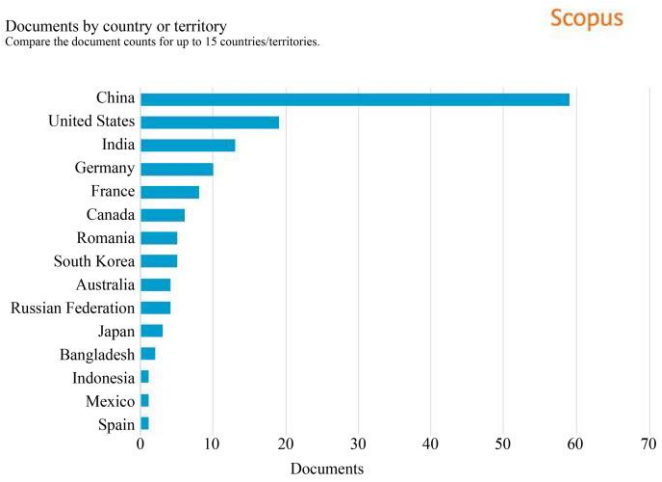

Fig. 5 Documents by territory

Figure 6 shows the distribution of documents by type, where scientific articles represent 54.5% of the total, while conference papers constitute the remaining 45.5%. This indicates a balance in the sources of scientific production, with a slight predominance of articles published in journals, suggesting a greater presence of consolidated and peer-reviewed studies compared to the results presented at academic events.

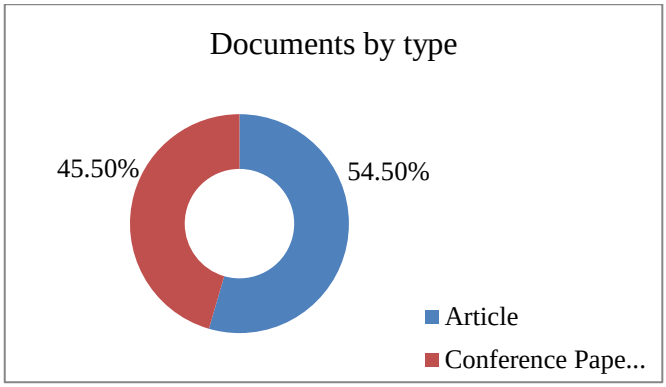

Fig. 6 Documents by type

The map in Figure 7 generated in VOSviewer presents a bibliometric analysis focused on the co-occurrence of terms related to “fog,” “traffic safety,” and “visibility.” Data were collected from scientific databases such as Scopus or Web of Science using keywords like “fog”, “traffic safety”, and “visibility”. These datasets were processed in VOSviewer, and specific fields (e.g., keywords or abstracts) were selected for analysis. A filtering process normalized the terms, establishing minimum frequency thresholds to include only the most relevant terms. The resulting map features nodes representing key concepts and connections, illustrating their co-occurrence within the texts. Colors indicate thematic clusters, while node size reflects the relative frequency of each term.

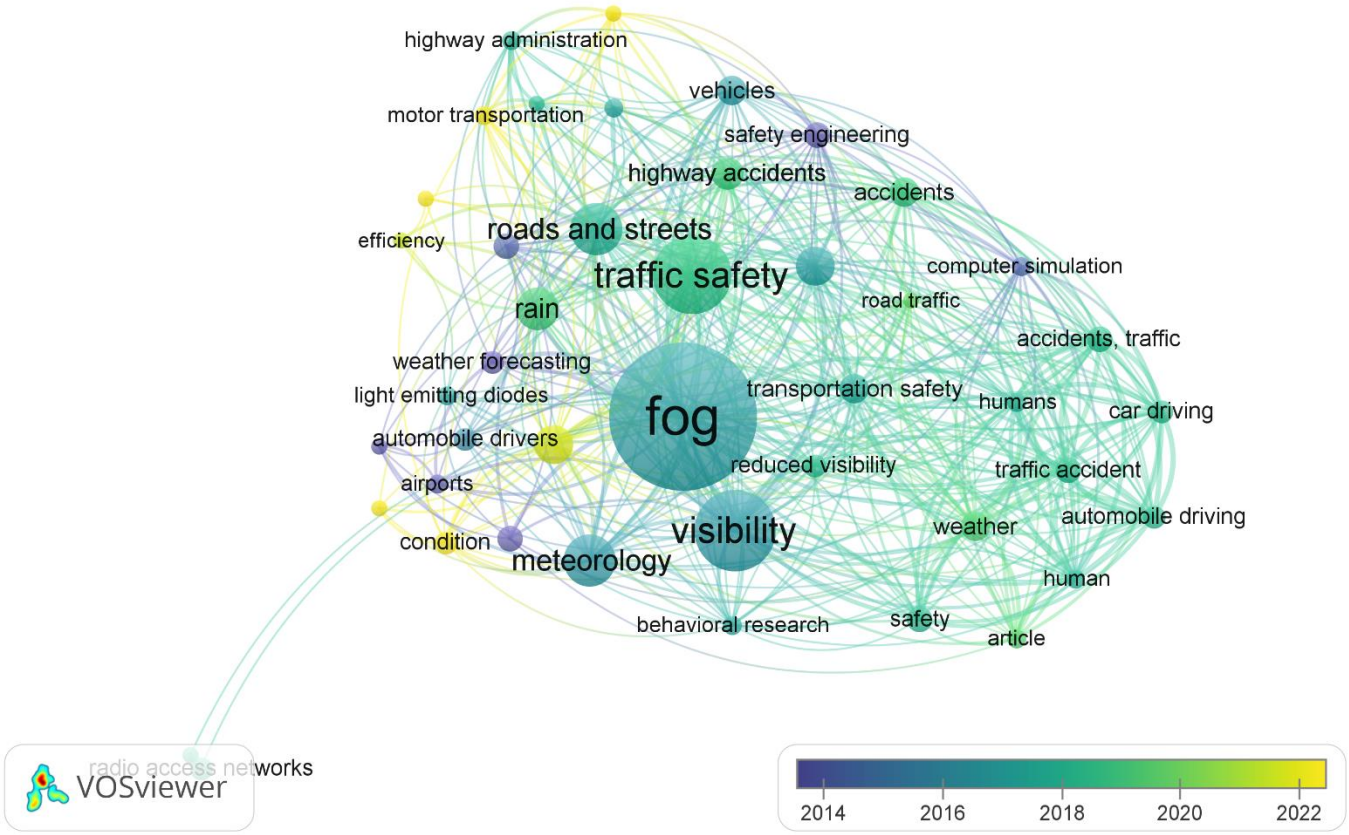

Fig. 7 Occurrences network

The visualization highlights key terms such as "fog," "traffic safety," and "visibility," which are central to the analyzed research. Clusters reveal thematic relationships: the green cluster associates terms linked to traffic safety and accidents, the blue cluster focuses on meteorological aspects like "visibility" and "reduced visibility," and the yellow cluster encompasses applied technologies such as "light emitting diodes" and "efficiency." Additionally, the temporal gradient of colors shows growing interest in specific terms like "traffic accidents" in recent years (2018–2022). This analysis not only identifies emerging trends but also highlights key connections between concepts, providing a comprehensive overview of future developments in this field.

4. Discussion and Conclusion

This research systematized the scientific production related to advanced technologies to mitigate accidents in foggy conditions. The results showed a progressive growth in publications since 2003, reaching a maximum of 17 papers in 2018 and showing a significant recovery in 2023 and 2024. This increase reflects a growing interest in the development of technological solutions applied to road safety in adverse conditions. As for the thematic areas, Engineering (34.7%) and Computer Science (25.0%) predominate, which shows the technical focus of the research. Other disciplines, such as Physics, Mathematics and Environmental Sciences, provide complementary perspectives although less representative.

On the other hand, the analysis by country or territory highlights China as the main contributor, with 67 documents (38%), followed by the United States and India, which reflects a geographical concentration in nations with high technological capacity. Regarding the type of documents, scientific articles (54.5%) slightly outperformed conference papers (45.5%), which demonstrates the predominant academic rigor in the studies identified. However, this distribution also suggests the importance of strengthening dissemination on collaborative platforms to diversify the channels of access to knowledge.

It is important to note that the systematic search was restricted to Scopus and IEEE Xplore, which, while guaranteeing the inclusion of high-quality publications, could have excluded relevant studies from other platforms such as PubMed, Dimensions, or regional databases. This limitation may affect the completeness of the analysis, so it is suggested that multiple sources be incorporated in future research to obtain a more complete and representative view of scientific production in this field.

We also identified difficulties in excluding irrelevant results due to ambiguous terms, such as "fog", used in non-meteorological contexts, such as neural networks. Although robust criteria were applied, potential biases persist that would require more thorough manual reviews or the application of additional filters early in the process. These challenges must be addressed to optimize the accuracy of the analysis and ensure the inclusion of truly relevant studies.

This research fulfilled its objective of analyzing advanced technologies to prevent traffic accidents in foggy conditions, highlighting trends and advances in road safety. There has been significant growth in scientific production since 2003, with a predominance in Engineering and Computer Science and a notable contribution from countries such as China and the United States. The results highlight the development of adaptive lighting systems, detection sensors and artificial intelligence algorithms, which have improved visibility and reduced the risk of collisions in low-visibility scenarios.
However, challenges remain that require further attention, such as the development of accessible sensing devices for regions with limited infrastructure. These devices could be integrated with early warning systems and real-time monitoring platforms to optimize road safety. It is recommended that reviews be expanded by incorporating additional databases and refining search filters for more accurate results and technological solutions adapted to diverse contexts.

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