Major Trends in In-Vehicle Head-Up Display Research: A Bibliometric Study

Jianan Lyu
School of Art and Design, Huizhou University, Huizhou, China

Abstract: This research is based on 816 documents from the Scopus database from 2015 to 2025 and uses bibliometric methods to analyze the study trends, cooperation networks, and intellectual evolution in the field of in-vehicle HUD. The research shows that the global annual publication volume has experienced three stages of fluctuating growth, reaching a peak of 98 articles in 2019 and rebounding to 97 articles in 2024, with an average annual growth rate of 31%. In terms of the characteristics of the research subjects, China leads in research output (169 articles, accounting for 20.7%) and influence (total citations 887 times), while the United States and Germany rank second and third respectively. The core authors are Gabbard JL (h-index = 13), Burnett G (h-index = 10), and Wang J (22 articles), who form the core cooperation network. The China-UK-Germany transnational cooperation cluster contributes 46% of the highly cited literature. In terms of the trend of intellectual evolution, augmented reality (AR-HUD) is the core research direction (keyword frequency 291 times), and the research interest increased by 300% from 2018 to 2022. In terms of technological transformation, it has shifted from optical design (2016-2018) to integration with autonomous driving (2021-2025), and panoramic HUD (P-HUD) was confirmed by CES 2025 as the next-generation key technology. In terms of the structure of the cooperation network, Germany, the Netherlands, and Sweden have formed a high-density cooperation sub-group in the group in Europe, and Singapore, as a bridge node, has promoted cross-regional technology integration (such as AR algorithms and waveguide design). This review is the first to reveal the interdisciplinary collaborative mechanism of HUD research through bibliometrics, providing empirical evidence for optimizing the R&D path and international cooperation strategies.

Keywords: Academics; Bibliometric Analysis; HUD; Augmented Reality

1. Introduction

The head-up display (HUD) emerged in the 1960s and was derived based on optical and radar targeting technologies. It was initially predominantly utilized in the domain of fighter aircraft [1]. This system is capable of projecting crucial driving information (such as fuel volume, rotational speed, etc) onto the driver's eye-level area on the front windshield of the vehicle, and it supports the adjustment of the display position and luminance [1]. This design enables drivers to obtain the requisite information conveniently without the frequent need to adjust the focus of their sight or shift their gaze range, effectively minimizing the action of drivers lowering their heads to check the instrument panel, thereby reducing the time that the eyes are diverted from the road ahead and significantly lowering the risk of traffic accidents resulting from distraction.

According to the differences in optical systems, HUDs are mainly classified into four types: C-HUD, W-HUD, AR-HUD, and P-HUD. Based on CES 2025, the development trend of HUD: P-HUD will be the key technological evolution direction for the next generation in-vehicle display system [2]. From the perspective of installation topology, the existing HUD systems mainly adopt two architectures: suspended and dashboard-mounted [1]. The suspended system is fixed to the sun visor area through a bracket and projects the image onto the upper half of the windscreen's field of view; the dashboard-mounted system is integrated at the front end of the dashboard and corresponds to the lower half of the windscreen's display area. These two architectures are respectively matched with different optical systems based on the imaging requirements to project information.

The installation volume of automotive HUDs has risen significantly [3]. In 2024, the number of new passenger vehicles in China equipped with HUDs reached 3.548 million, a year-on-year increase of 63.0%, with the installation rate rising to 15.5%. The global automotive HUD market is expected to grow from $2 billion in 2021 to $4.5 billion in 2030, with a compound annual growth rate of 31% during this period [4]. Key factors driving this trend include the development of emerging technologies such as photonics, augmented reality (AR), the Internet of Things (IoT), and autonomous driving systems, which provide a broad space for the diverse application of HUDs [5].

Historically, propelled by technological progress, researchers have carried out more extensive investigations into the applications of automotive HUDs. Some studies have concentrated on leveraging HUDs to enhance driving performance and safety. For instance, efforts have been made to alleviate the cognitive burden on drivers[6-8], enhance driving comfort [9-11], and explore applications within navigation scenarios [10, 11]. Concurrently, research has also delved into the applications of HUDs in non-driving-related tasks, including information and entertainment scenarios as well as the realm of artificial intelligence [12].

The bibliometrics employed in this paper is an interdisciplinary science that conducts quantitative analysis on various knowledge carriers by means of mathematical and statistical methods [13, 14]. This field integrates mathematics, statistics, and linguistics to form a comprehensive knowledge system, with its core being quantitative analysis. Generally, bibliometric methods are used to evaluate published scientific literature, which helps to clarify the fundamentals, hotspots, and frontier dynamics within a specific research field [15], and provides statistical overviews for various activities in the scientific community [15, 16]. Currently, it has been widely applied in the assessment of scientific progress in multiple scientific and engineering disciplines. In this paper, we apply bibliometric analysis methods to the field of in-vehicle HUDs, aiming to reveal the main research trends and important development directions in this field, as well as to identify the key research areas that have a significant impact on HUDs.

This study covers 816 papers related to HUD in the Scopus database from 2015 to 2025, aiming to deeply analyze the current study trends. Specifically, we conducted a systematic analysis of multiple dimensions including literature types, publication numbers, national contributions, Scopus top categories, journal information, high-yield authors, research fields, and author keywords. Given the wide range of research areas covered by keywords plus, our analysis results are of great reference value to HUD researchers. This study not only comprehensively summarizes the research trends in the HUD field but also accurately identifies key areas that cannot be ignored in future research, and conducts in-depth discussions on the HUD-related fields, helping researchers grasp the research directions of great concern, the structure of this paper is clear, with the second section elaborating on the research methods, the third section presenting the research results, the fourth section deeply discussing the 20 most cited papers in the HUD area, and the fifth section providing a comprehensive summary of this research work.

2. Methodology

This study focused on HUD technology and compared two major databases, Web of Science (WoS) and Scopus [13, 17, 18]. WoS is renowned for its high reliability in literature retrieval and analysis, while Scopus has a broader coverage of journals [13, 19]. To select the appropriate database, the search terms "(Head*up*display* or HUD*) and (car or sedan or vehicle or automotive or driving or driver or autonomous vehicle)" were used in both databases. WoS returned 315 articles, while Scopus had 1547, covering the period from 2015 to 2025. As the Scopus database contains a more abundant number of documents, the relevant data was extracted from this database on May 31, 2025.

To focus on recent research, this survey was limited to achievements between 2015 and 2025. Initially, 1,547 relevant documents were screened out. After refining the criteria, the number was reduced to 985. Further narrowing the focus to key disciplines such as computer science, engineering, and mathematics, the number of documents was adjusted to 950. Finally, after carefully reading the titles and abstracts and eliminating 134 papers with weak relevance to in-vehicle HUD technology were determined. These documents comprehensively cover the major research achievements and trends in this field from 2015 to 2025.

The data for this research mainly originated from the Scopus database, which included indexed publications with the terms "(Head*up*display* or HUD*) and (car or sedan or vehicle or automotive or driving or driver or autonomous vehicle)" in their titles, abstracts, or keywords. Despite the limitation that authors might use synonyms, approximately 95% of the relevant publications were simultaneously indexed in Scopus and Wed of Science (WoS). Although WoS is one of the most trusted and large-scale databases in the field of literature retrieval and analysis, Scopus has a broader coverage of journals. Therefore, publications indexed in WoS were not included in the analysis of this study. The majority of the publications in Scopus represent significant achievements in the research of in-vehicle HUDs, and the data were processed and analyzed using the VOSviewer and Bibliometric software package version 4.5.

As shown in Figure 1, this study presents the data collection process.

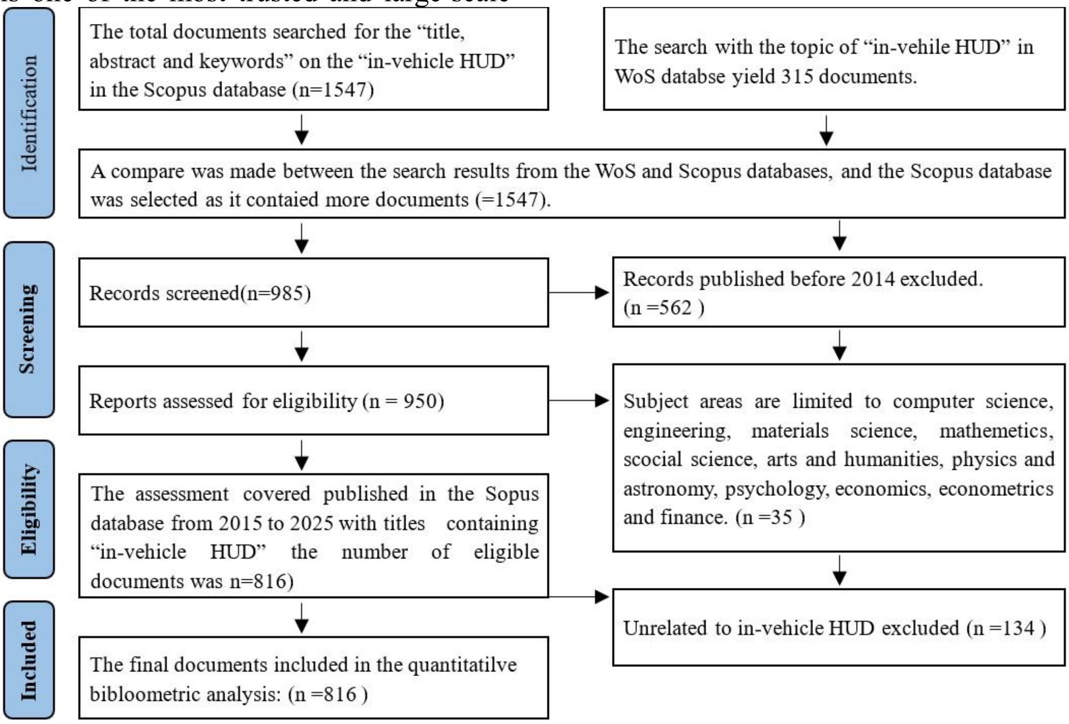

Figure 1. PRISMA Flowchart Illustrating the Literature Collection Process for in-vehicle HUD

Table 1. The Main Information about 816 Articles on in-vehicle HUD

Description	Results
Period	2015:2025
Sources	335
Documents	816
Average citations per doc	9.684
Keywords plus	4402
Author's keywords	1907
Authors	2417
Authors of single-authored docs	53
Single-authored docs	58
Co-Authors per Doc	4.16
International co-authorships %	14.71
article	318
book chapter	22
conference paper	464
review	11
short survey	1

Table 1 presents the information of 816 documents in the field of in-vehicle HUD from the Scopus database. From 2015 to 2025, the database included 464 conference papers, 318 journal articles, 11 reviews, 22 book chapters, and 1 short review. To grasp the sub-theme of in-vehicle HUD research, this study conducted a qualitative analysis of the top 20 highly cited documents. The following text will carry out quantitative and qualitative research on the data.

3. Quantitative Analysis

3.1 Sources Analysis

As presented in Table 1, there are 335 sources within this bibliographic collection, including journals, books, and other types.

3.1.1 Most relevant sources

Figure 2 reveals ten key information sources in the field of in-vehicle HUDs. The Digest of

Technical Papers – SID International Symposium, the top journal in the field of in-vehicle HUDs, has published 52 related papers from 2015 to 2025. The Proceedings of the SPIE – the International Society for Optical Engineering follow closely behind, with 48 papers on in-vehicle HUD research. The Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics) ranks third with 38 papers. Other journals have published over 12 documents in this analytical dataset. The three top-ranked journals in Figure 2 hold substantial significance for researchers in the field of in-vehicle HUD. Submission of research works to these journals may be prioritized.

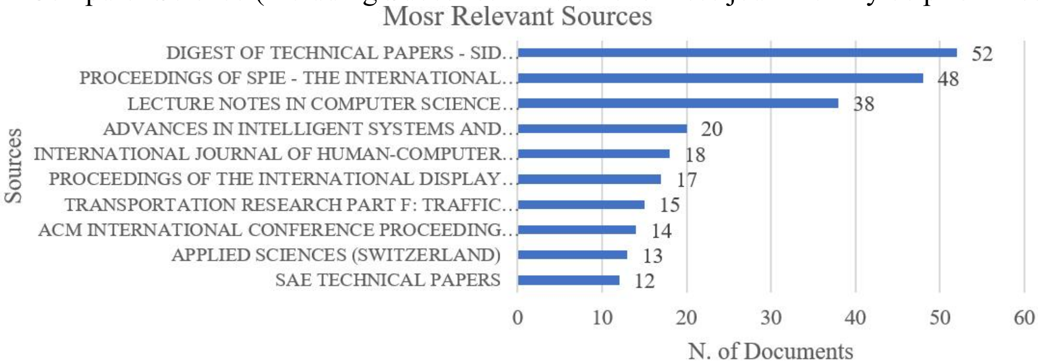

Figure 2. The Top 10 Sources of in-vehicle HUD Documents Releases from 2015 and 2025

Figure 3 presents the frequencies of occurrences of various sources during the period from 2015 to 2025. This figure reveals the most influential sources within the domain of in-vehicle HUD. As time progresses, the annual number of relevant articles published in top-tier journals has been on the increase. The "Digest of Technical Papers – SID International Society for Optical Engineering" and three other journals have shown an upward trend.

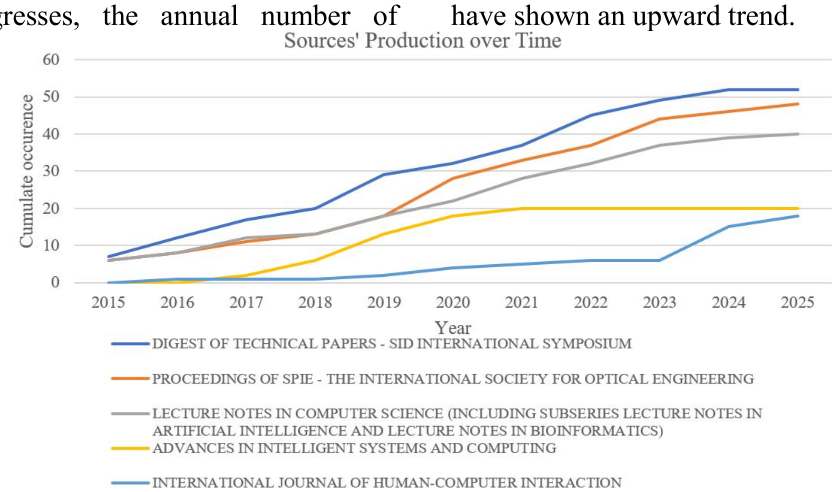

Figure 3. Annual Publication of the Top 5 Sources in the in-vehicle HUD from 2015 to 2025

3.1.2 Analysis of sources impact

Table 2 depicts the impact indicators of scientific literature associated with in-vehicle HUD from 2015 to 2025. These indicators encompass the h_index, g_index, total citation frequency, number of papers, and publication year.

Journals and conferences such as Transportation Research Part F exhibit a notable influence within this domain. With an h-index of 10, it implies that there are 10 papers published that have been cited at least 10 times. The Digest of Technical Papers – SID International Symposium demonstrates the highest total citation frequency, amounting to 229.

Substantial variances are evident among different publications in terms of both quantity and influence. For example, the Digest of Technical Papers – SID International Symposium contains the largest number of papers (n=52), while Accident Analysis and Prevention has a relatively small number of papers (n=8), yet it boasts a total citation frequency of 181.

These data play a crucial role in enabling researchers to comprehensively understand the distribution and influence of research outcomes in the in-vehicle HUD field. Consequently, they offer valuable insights for researchers when determining research directions and selecting appropriate publication platforms.

Table 2. The Source Impact Index within 2015 - 2025

Source	h_index	g_index	m_ index	TC	NP	PY_start
Transportation Research Part F: Traffic Psychology and Behaviour	10	14	1.25	219	15	2018
International Journal of Human-Computer Interaction	9	12	.900	168	18	2016
Accident Analysis and Prevention	8	8	.727	181	8	2015
Digest of Technical Papers - SID International Symposium	8	13	.727	229	52	2015
IEEE Access	7	10	.875	136	10	2018
IEEE Conference on Intelligent Transportation Systems, Proceedings, ITSC	7	7	.636	183	7	2015
Applied Optics	6	11	.750	222	11	2018
Applied Sciences (Switzerland)	6	13	1	201	13	2020
Optics Express	6	7	1	130	7	2020
Proceedings of SPIE - the International Society for Optical Engineering	6	10	.545	157	48	2015

3.1.3 Publication years analysis

Figure 4 presents the number of publications in the field of in-vehicle HUD from 2015 to 2025. Over these ten years, a total of 816 academic works were published. The distribution of in-vehicle HUD publications can be classified into three phases.

In the first phase (2015 - 2019), with the rapid advancement of technology, the field attracted the attention of numerous researchers. As a result, the number of publications increased steadily. Starting from 77 in 2015, it gradually climbed year by year and reached a peak of 98 in 2019.

During the second phase (2019 - 2022), the number of publications exhibited fluctuations, declining from 98 in 2019 to 75 in 2022.

Upon entering the third phase, with an increasing number of researchers dedicating themselves to this field, the number of publications ascended once more. In 2024, it neared the highest value of 2019, reaching 97.

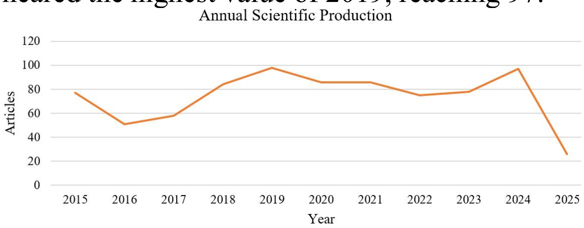

Figure 4. Annual Scientific Output in the Field of HUDs for Vehicles from 2015 to 2025

3.2 Analysis of Authors in the Hud Research Area

Table 1 shows, that from 2015 to 2025, 816 research achievements in the field of in-vehicle HUDs were published by 2417 researchers in the Scopus database, with an average of 2.962 co-authors per document. This section aims to analyze the authorship situation in the field of in-vehicle HUDs.

3.2.1 Analysis of most relevant authors

Table 3 lists the most productive authors in the field of HUD for vehicles from 2015 to 2025. Gabbard JL ranked first with 23 papers, followed by Wang J (22 papers) and Zhang Y (19 papers). This reflects the high level of research activity and influence in this field, which is of great significance for promoting technological innovation and application. Authors such as You F and Wang Y have also contributed a large number of research results, further confirming the fact that numerous scholars are jointly promoting the development of academic research and knowledge accumulation in the field of in-vehicle HUDs.

Collaborative research analysis can quantify the differences in authors' contributions to collaborative research by comparing the number of publications with the article fractionation score. For example, Kim H has published 17 articles but received a score of 5.33, indicating that they play a core role in team collaboration and have made outstanding contributions to project progress and outcome output. This type of collaborative model is commonly found in the research of in-vehicle HUD, as it involves interdisciplinary fields such as human factors engineering, display technology, and driving cognition, requiring cross-disciplinary teams to collaborate and tackle complex technical challenges.

Table 3. Most Relevant Authors with 2015-2025

Authors	Articles	Articles Fractionalized
GABBARD JL	23	6.53
WANG J	22	4.35
ZHANG Y	19	3.39
WANG Y	18	3.16
ZHANG J	18	2.98
BURNETT G	17	4.03
KIM H	17	5.33
LIU Y	16	2.94

YOU F	16	3.32
LI Y	15	3.38

3.2.2 Analysis of the authors' impact

This section quantitatively assesses the influence of researchers in the field of in-vehicle HUDs by using indicators such as the h-index, g-index, m-index, total citation count (TC), and number of papers (NP). Table 4 shows that Gabbard JL stands out in terms of influence, with an h-index of 13, a g-index of 23, and a total citation count as high as 558, indicating that his research results have been widely cited and have high academic value. Burnett G and Kim H follow closely behind, with h-indices of 10 and 9 respectively, and TCs of 331 and 352 respectively, demonstrating their deep accumulation in the field of in-vehicle-HUD. In addition, although researchers such as Riener A and Smith M perform slightly weaker in some indicators, their m-index and NP also show their activity and potential in this field.

Overall, these are significant differences in the influence of researchers in the field of in-vehicle HUD. Early entrants such as Gabbard JL and Burnett G have taken the lead with their rich research results and high citation counts. Meanwhile, new entrants such as Riener A and Park J have also shown certain competitiveness.

Table 4. Authors' Local Impact in in-vehicle within 2015-2025

Author	**h-index**	**g-index**	m-index	TC	NP	**PY_Start**
GABBARD JL	13	23	1.182	558	23	2015
BURNETT G	10	17	.909	331	17	2015
KIM H	9	17	.900	352	17	2016
RIENER A	9	10	1.125	262	10	2018
SMITH M	9	10	.818	234	10	2015
PARK J	8	13	1.000	295	13	2018
CHARISSIS V	7	12	.778	163	14	2017
WANG J	7	9	.778	101	22	2017
WANG Y	7	11	.875	134	18	2018
YANG Z	7	10	1.000	117	14	2019

3.2.3 Analysis of most relevant affiliation

As shown in Figure 5, Zhejiang SCI-TECH University ranks first with 71 achievements in the research of HUDs, indicating its high activity and significant influence in basic research, technological development, and application. Tongji University (46 articles) and Changchun University of Science and Technology (39 articles) rank second and third, indicating their advantages in key technologies or specific application directions. Other affiliations such as Glasgow Caledonian University and the University of Central Florida have published between 18 and 33 articles, presenting diverse research results. In addition such as Zhejiang University is 23, highlighting the breadth of research in this field. In summary, these affiliations each have their characteristics and constitute an important force in the research of HUDs, enriching the theoretical system of this technology and promoting its industry application.

Figure 6 shows the publications of the top 5 affiliations over time.

3.2.4 Analysis of most cited counties

Figure 7 shows that from 2015 to 2025, China has been cited 887 times in the field of HUD research, ranking first, indicating its research influence. The United States (817 times), Germany (482 times), and Japan (419 times) ranked second, indicating that these countries have a high influence and contribution to HUD research. Other countries such as Italy, the United Kingdom, India, Australia, and Switzerland are relatively less frequently cited.

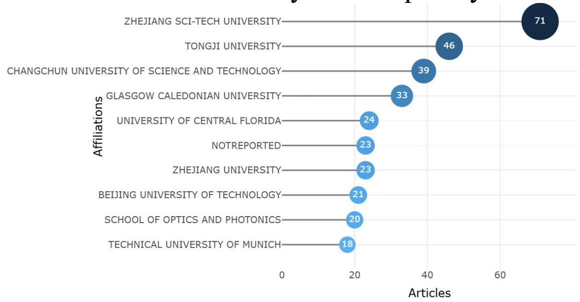

Figure 5. Most Relevant Affiliations in HUD Research Area from 2015 to 2025

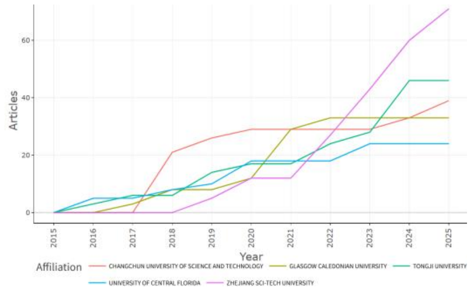

Figure 6. Affiliations' Production over Time in the HUD Research Area

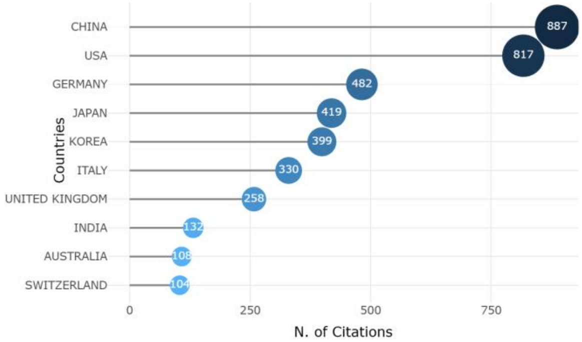

Figure 7. Most Cited Countries in the HUD Research Area from 2015 to 2025

3.2.5 Analysis of corresponding author's countries

As shown in Figure 8, the corresponding author's country information shows that China holds a dominant position in the research of HUDs, with a total of 169 articles published (20.7%), of which multiple collaborative papers (MCP) account for 12.4%, indicating that China has a broad research foundation and active cooperation in this field. Germany (55 articles, 6.7%) and the United States (48 articles, 5.9%) ranked second and third respectively, with MCP ratios of 9.1% and 27.1%, indicating high research output and frequent cooperation and exchange. South Korea (43 articles) and the UK (28 articles) also performed outstandingly, with South Korea's MCP ratio reaching 14%. Japan, India, and other countries have relatively fewer publications, but they have also made certain contributions. Other countries such as Italy, Canada, and France, have fewer publications. In short, each country has its focus on research in this field. China leads development with its significant advantages, while other countries have also promoted technological progress through cooperation and research.

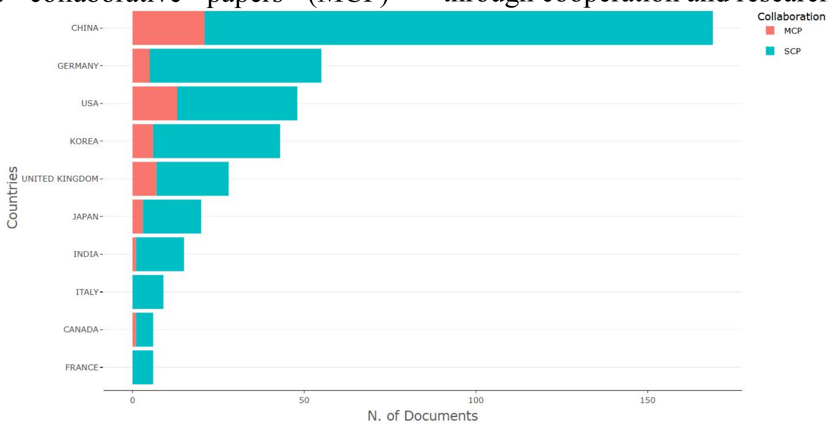

Figure 8. Corresponding Author's Countries in the HUD Research Field from 2015 to 2025

3.3 Documents Analysis

3.3.1 Analysis of the top ten documents

Table 5 summarizes the top 10 documents globally in terms of total citations per year (TCpY), covering fields such as autonomous driving, intelligent transportation, and human-computer interaction. The documents were published between 2015 and 2022 in well-known journals and conferences, including Nature Communications and IEEE Transactions on Vehicular Technology. The total citations range from 295 to 45, with an average annual citation rate of 29.5 to 9 times per year.

These documents not only reflect the research hotspots in relevant fields but also show the trend of interdisciplinary research, providing important references for research in autonomous driving, intelligent transportation, and other fields.

Table 5. The Top Ten Documents Based on the Average Annual Citation Count in the Scopus Database

No.	Author	Title	Source	Year	TC	TCpY
1	Wakunami, K., Hsieh, PY., Oi, R. et al.	Projection-type see-through holographic three-dimensional display [20]	Nature Communications	2016	295	29.50
2	Marai, O. E. Taleb, T. Song, J.	Roads Infrastructure Digital Twin: A Step Toward Smarter Cities Realization [21]	IEEE Network	2021	122	24.40
3	Liu, T. Yan, R. Huang, H. et al.	A Micromolding Method for Transparent and Flexible Thin-Film Supercapacitors and Hybrid Supercapacitors [22]	Advanced Functional Materials	2020	104	17.33
4	Morra, L. Lamberti, F. Gabriele Prattico, F. et	Building Trust in Autonomous Vehicles: Role of Virtual Reality Driving	IEEE Transactions on	2019	119	17.00

	al.	Simulators in HMI Design [23]	Vehicular Technology			
5	Kim, H. Gabbard, J. L.	Assessing Distraction Potential of Augmented Reality Head-Up Displays for Vehicle Drivers [24]	Human Factors	2022	68	17.00
6	Wu, Y. Abdel-Aty, M. Park, J. et al.	Effects of crash warning systems on rear-end crash avoidance behavior under fog conditions [25]	Transportation Research Part C: Emerging Technologies	2018	119	14.88
7	Wang, Z. Liao, X. Wang, C. et al.	Driver Behavior Modeling Using Game Engine and Real Vehicle: A Learning-Based Approach [26]	IEEE Transactions on Intelligent Vehicles	2020	82	13.67
8	Pavel, M. I. Tan, S. Y. Abdullah, A.	Vision-Based Autonomous Vehicle Systems Based on Deep Learning: A Systematic Literature Review [27]	Applied Sciences (Switzerland)	2022	51	12.75
9	Borghi, G. Fabbri, M. Vezzani, R. et al.	Face-from-Depth for Head Pose Estimation on Depth Images [28]	IEEE Transactions on Pattern Analysis and Machine Intelligence	2020	72	12.00
10	Skirnewskaja, J. Wilkinson, T. D.	Automotive Holographic Head-Up Displays [29]	Advanced Materials	2022	47	11.75

3.3.2 Analysis of the most frequent words

As shown in Table 6, The latest bibliometric analysis indicates that HUDs have emerged 835 times in relevant research domains, underscoring their extensive application prospects in fields such as automotive driving, aviation, and the military. By projecting crucial information directly into the driver's sight, HUDs minimize the need for visual shifts, thereby enhancing driving safety and efficiency.

High-frequency keywords closely associated with HUDs include augmented reality (291 occurrences), user interface (70 occurrences), optical design (60 occurrences), and autonomous vehicles (47 occurrences). Augmented reality technology significantly enhances the information display capabilities of HUDs, while optical design ensures clear visualization under diverse conditions. The advancement of autonomous driving technology presents novel opportunities for HUDs, enabling them to assume a more substantial role in intelligent information display and interaction.

Driving simulators (50 occurrences) and behavioral research (53 occurrences) also constitute significant research avenues for HUDs. Driving simulators are employed to assess the performances of HUDs, while behavioral research focuses on the drivers' usage experiences, providing a foundation for optimizing the design. In the future, HUD technology will center on enhancing display quality, refining the user experience, and adapting to autonomous driving scenarios, thus facilitating its widespread adoption in the transportation sector.

Table 6. The Top Twenty Frequent Keywords

No.	Words	Occurrences
1	head-up displays/head up displays/head-up display/heads-up-display	835
2	augmented reality	291
3	automobile drivers	142
4	vehicles	86
5	helmet mounted displays	80
6	user interfaces	70
7	virtual reality	64
8	human computer interaction	60
9	optical design	60
10	roads and streets	60
11	display devices	59
12	behavioral research	53
13	holographic displays	53
14	automation	50
15	driving simulator	50
16	autonomous vehicles	47
17	automotives	46
18	windshields	44
19	female	43
20	human	43

3.3.3 Analysis of the word cloud of the author's keywords

From Figure 9 word cloud of the author's keywords, it can be seen that "augmented reality " and " head-up display" are the core themes, indicating that they are the research hotspots and key directions. Related terms such as "automotive augmented reality head-up display" and "augmented reality head-up display" frequently appear, highlighting the importance of augmented reality in the field of HUD. Additionally, keywords like "virtual reality", "head-up display", and "driving simulator" reflect the extensive exploration of HUD technology in multiple scenarios.

Meanwhile, the appearance of terms such as "autonomous driving", "intelligent vehicle", and "accident prevention" shows the deep integration of HUD technology with autonomous driving, vehicle intelligence, and driving safety. "Human-machine interaction" and "user interface" reflect the focus on user interaction experience, aiming to enhance the user experience and operational convenience. "Optical design" and "display equipment" indicate that optical and display technologies, as the foundation of HUD, remain important research areas.

In summary, the word cloud provides researchers with a visual and crucial reference for grasping the research trends and future directions of HUD.

Figure 9. Word cloud of the Author's Keyword

3.3.4 Analysis of the trend topics

By analyzing terms in Table 7, it is found that the current research hotspots in the field of technology are mainly focused on “augmented reality” and “virtual reality”. Augment reality has become the most popular research direction with a high frequency of 291 times, and its research popularity has continued to rise since 2018, reaching its peak in 2022. The research enthusiasm for virtual reality cannot be underestimated, with a frequency of 64 times and a period of 2018-2021, indicating that this field has also received high attention in recent years.

In addition, although the frequency of “computer simulation” is relatively low (28 times), its Q3 year is 2023, indicating that this field may be an emerging research direction that has begun to receive more attention in recent years. In contrast, research on Head Up Displays and Display Devices has been focused on the years 2016-2018, indicating that these fields received more attention in the early stages, but their popularity has declined in recent years.

In summary, “augmented reality” and “virtual reality” are currently hot research areas, and their popularity continues to rise, “computer simulation” is an emerging research direction; “head-up display Devices” belong to the early popular fields but have experienced a decline in popularity in recent years.

Table 7. Trend Terms, During 2015-2025, in the HUDs Research Area in the Scopus Database

No.	Term	Frequency	Year (Q1)	Year (Median)	Year (Q3)
1	head up displays	132	2016	2017	2018
2	optical design	60	2016	2017	2020
3	display devices	59	2016	2017	2018
4	human computer interaction	60	2016	2018	2020
5	accident prevention	28	2017	2018	2022
6	computer simulation	28	2015	2018	2023
7	vehicles	86	2017	2019	2021
8	user interfaces	70	2017	2019	2021
9	virtual reality	64	2018	2019	2021
10	augmented reality	291	2018	2020	2022

Figure 10 shows the trend topics in the HUD area, the early research focused on fundamental technical areas such as “optical design”, “display devices” and “human-computer interaction”, aiming to enhance the display effect and user experience of HUDs. With the maturation of technology and changes in market demand, research hotspots have gradually shifted toward application fields such as “augmented reality”, “autonomous driving”, and “panoramic HUDs”. Particularly after 2018, the keyword frequency of “augmented reality” has significantly increased, indicating that its application in HUDs has become a research hotspot. Meanwhile, the research interest in topics like “holographic displays” and “autonomous vehicles” has also been on the rise, reflecting the trend of technology towards intelligence and integration. In contrast, the research interest in traditional topics such as “helmet-mounted displays” and “head-up displays” has remained relatively stable, suggesting their continuous application in specific fields. Overall, the research themes of HUDs have evolved from fundamental technologies to diversified applications, demonstrating the dynamic changes in technological progress and market demand.

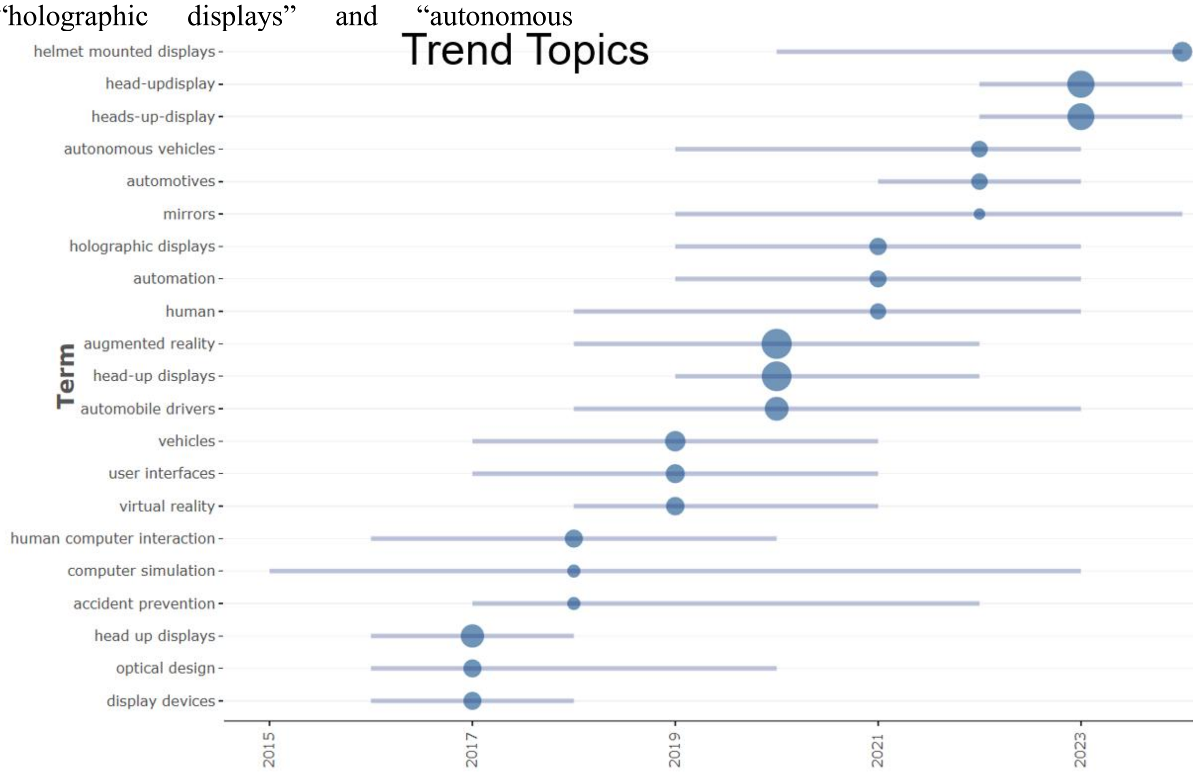

Figure 10. Trend Chart of Hot Topics in-Vehicle HUD Research in the Scopus Database from 2015 to 2025

3.4 Analysis of the Conceptual Structure

3.4.1 Analysis of the thematic map

This thematic map classifies themes into four quadrants based on two dimensions: relevance and development level, as shown in Figure 11. The top left quadrant represents niche themes, such as “human” and “driving”, which have low relevance but high development level. The top right quadrant represents mainstream themes, such as “head-up display”, which have high relevance and high development level. The lower left quadrant represents emerging or declining themes, which have relatively low popularity. The bottom right quadrant represents fundamental themes, such as “augmented reality”, which have high relevance but low development level, indicating potential. Themes in the middle area, such as “helmet display”, have moderate relevance and development level. This map helps identify current hotspots and fundamental and potential themes and has significant reference value for choosing research topics in the field of in-vehicle HUD.

3.4.2 Analysis of co-occurrence network in the hud area

The co-occurrence network graph is used to visually present the association among different concepts or themes. In the graph, nodes represent specific concepts or themes, and the size of the nodes reflects their importance or centrality in the network, that is, their frequency of occurrence or the number of connections. The lines connecting the nodes indicate the frequency of co-occurrence of these concepts in a specific context, and the thickness of the lines may reflect the strength of co-occurrence.

As shown in Figure 12, Several core themes can be identified from this diagram. These themes, as key nodes in the network, are associated with numerous other nodes. For example, "augmented reality", and "head-up display" are core themes in the graph, occupying a central position in the network, indicating that these themes are very important in the discussion and have close connections with many other themes.

In addition, several theme groups are formed in the graph, where the concepts or themes within these groups have many co-occurrence relationships. For instance, the theme group related to "augmented reality" may include "virtual reality", "mixed reality", etc., which are often mentioned together in the field of technology. Similarly," head-u display" may form a group with "autonomous driving", "vehicle navigation", etc., because these themes are closely related in the field of automotive technology.

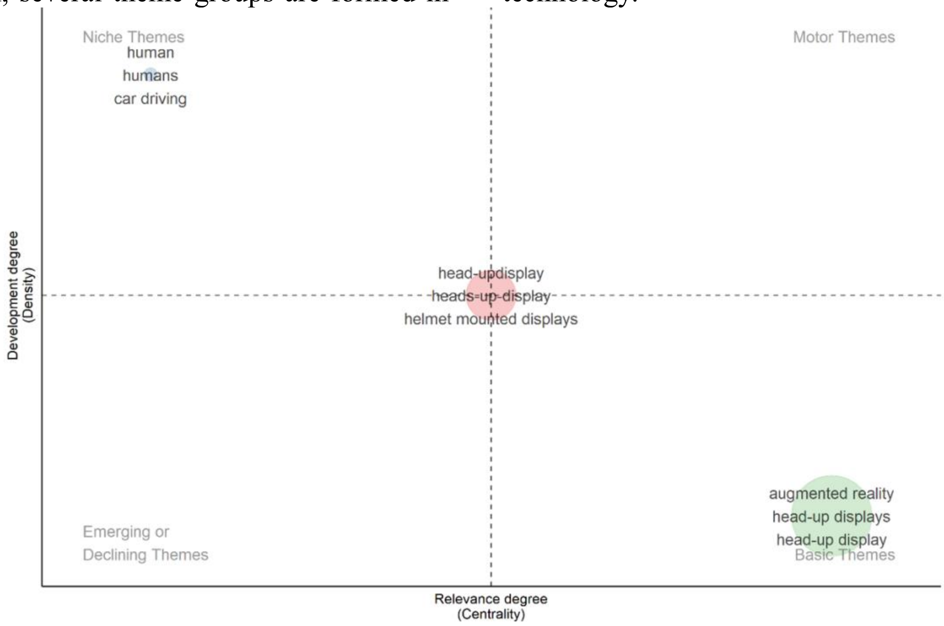

Figure 11. Thematic Map of In-Vehicle HUD Field Publications from 2015 to 2025

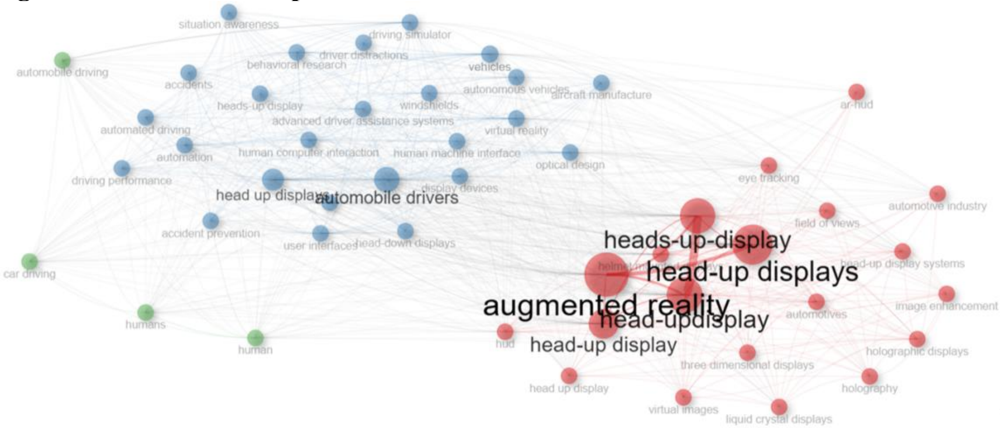

Figure 12. Co-Occurrence Network in HUD Research Area from 2015 to 2025

3.5 Analysis of the Social Structure

3.5.1 Analysis of collaboration network among countries

As shown in Figure 13, in the field of HUD technology research and development, the international cooperation network exhibits characteristics of multi-polarization and clustering. The international cooperation network exhibits characteristics of multi-polarization and clustering. Through the analysis of academic cooperation network data from 28 countries and regions worldwide (including major automotive industrial countries such as Germany, the United States, China, South Korea, and Japan, as well as innovation-active regions like Singapore and Finland), it is found that:

Core countries lead innovation: Germany, the United States, China, Japan, and South Korea, with their mature automotive industrial chains and abundant R&D resources, occupy the core positions in the network (with high centrality indicators) and play the role of technology diffusion hubs.

The regional cluster effect is significant: in Europe, close cooperation subgroups have formed (such as Germany – the Netherlands – Sweden – Austria), while in Asia, China, Japan, and South Korea serve as the core to radiate to Southeast Asia (Malaysia Singapore).

Countries like Singapore and the Netherlands play a key role in cross-regional cooperation, for instance, connecting Europe, America, and Asia, and promoting the integration of specific technologies such as optical display and augmented reality algorithms.

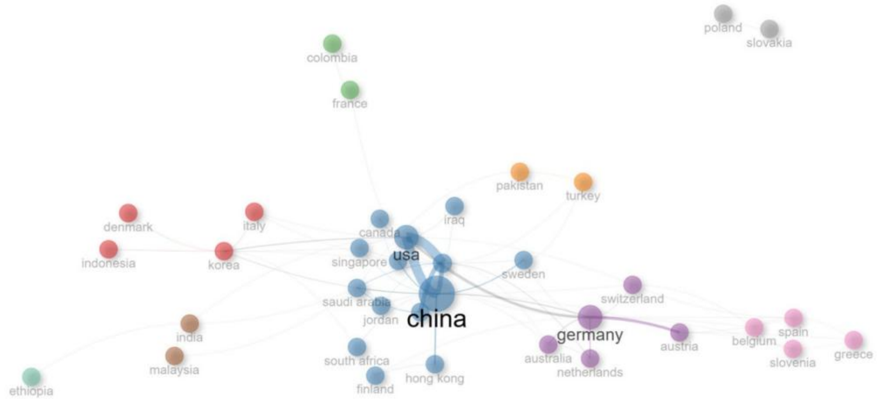

Figure 13. Collaboration Network among Countries in the HUD Area from 2015 to 2025

3.5.2 Analysis of collaboration network among authors

In the analysis of the collaborative network in the field of HUDs, it was found that as shown in Figure 14, “Wang J” is at the core, closely cooperating with “Li Y”, “Zhang Y” and other entities to form a stable core team and lead the research direction. There are also two secondary cooperative groups, “Burnett G,” “Skrpchunk I,” “Li K,” and “Gabbard JL,” “Riener A,” which are small in scale and slightly less closely knit but also contribute unique strengths. “Park J”, “Lee J”, “Yang Z”, “Sun Y”, “Chen X”, “Wang S”, and “Charissis V”. The author is relatively independent and only occasionally collaborates, with “Charissis V” and “Wang S” having some cooperation. Overall, the core team has frequent internal cooperation and close communication, forming a highly cohesive research community, while the periphery is relatively loose, presenting a pattern of diverse cooperation led by the core team. The research direction of the core author group represents the mainstream trends and hotspots in the field, which makes it easy to attract researchers to join and promote in-depth expansion. The focus of secondary collaborative groups and independent authors is complementary to mainstream research or emerging fields, providing extensive exploration space and potential development directions for research.

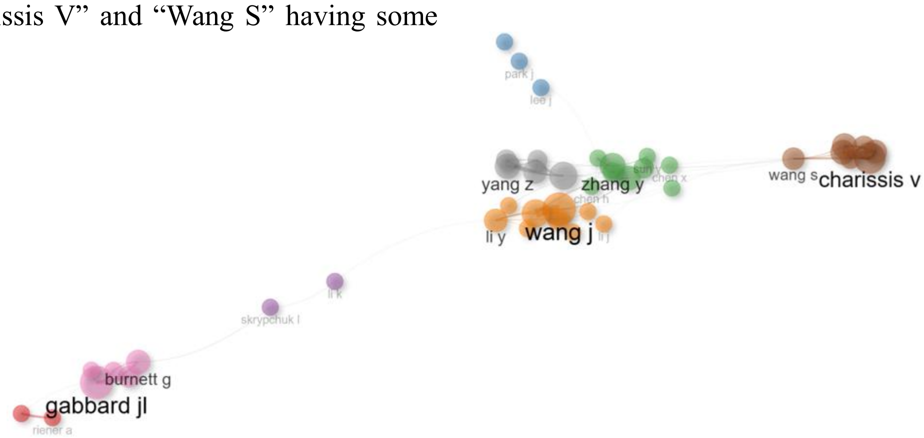

Figure 14. Collaboration Network among Authors in the HUD Area from 2015 to 2025

3.6 Visualization of Cross-Data-Platform Topic Association Analysis

Figure 15 summarizes the occurrence frequencies of different themes and keywords in 816 Scopus subject categories. Generally, the proximity between two themes reflects their correlation, while the size of the subject category indicates the number of publications related to that theme. The colors range from purple to yellow, representing the differences in publication time of the subject categories. Purple marks earlier publications, while yellow marks newer ones.

As depicted in Figure 15, the early works on HUD in the Scopus database were often closely associated with topics such as "user interfaces", "optical design", "head up display", "driving simulator", "vehicles", and "display devices". In the more recent publications, the research on HUD in Scopus is related to "automated driving", "automated vehicle", "ar-hud", "helmet-mounted displays", and "head up display". Publications after 2021 have placed greater emphasis on "automated driving" and "ar-hud".

The analysis results of visualize topic analysis in this section are consistent with section 3.3.3 analysis of the trend topics and section 3.4.1 analysis of the theoretical map.

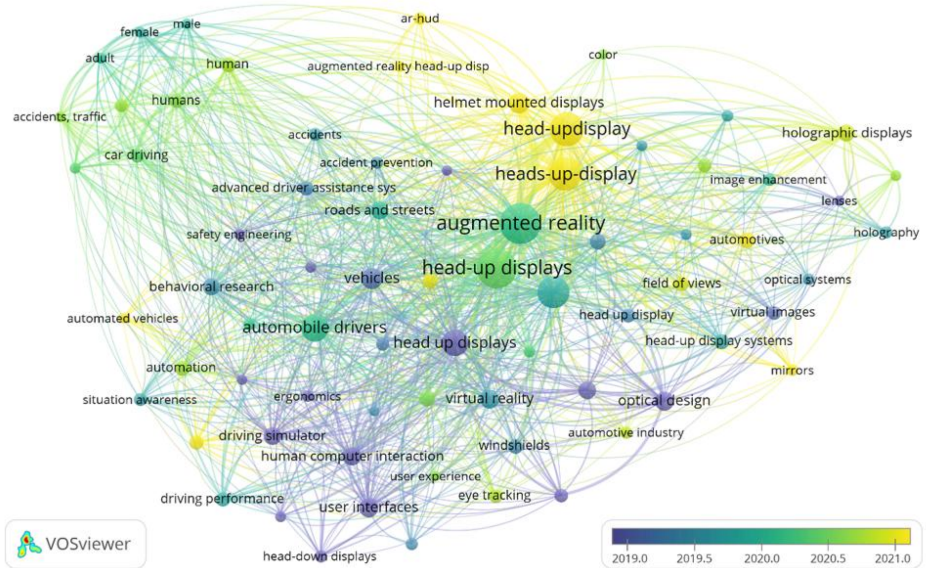

Figure 15. Map of Articles during 2015-2025, Bibliographic Coupling, HUD in Scopus Database

4. Discussion

Bibliometrics is highly objective and can reduce the influence of subjective factors on research results, thus having more advantages than peer review. However, it also has some limitations. To overcome these limitations, it is necessary to combine the qualitative analysis of relevant scholars and their active fields with the objective data of bibliometrics [13, 30, 31].

An in-depth exploration of the top 20 literature can help us grasp the latest trends and research hotspots in the field of HUDs, including augmented reality, helmet-mounted displays, and autonomous vehicles, to keep up with the latest developments in academic research. This section reviews the top 20 articles in the field of HUD research from 2015 to 2025, aiming to analyze the research trends and key directions in this field through econometric methods. These articles cover multiple aspects of HUD technology, including technological innovation, application areas, user experience, and security.

The combination of AR and HUD is one of the key research directions in this field, especially prominent in the automotive sector. Wakunami K. et al. [20] successfully developed a projection-type holographic three-dimensional display, which effectively expanded the display size and viewing angle by integrating digitally designed holographic optical elements with digital holographic projection technology. Kim and Gabbard [24] proposed a new method for evaluating AR HUD and found that well-designed AR interfaces can significantly enhance drivers' awareness of key road elements such as pedestrians.

In the realm of holographic display technology, researchers have devised numerous holographic display solutions. The research conducted by Wakunami K. et al. [20] reveals that this technology is capable of enhancing the display size by a factor of two and the viewing angle by a factor of six. This achievement paves the way for the application of HUD in fields such as digital signage and in-vehicle HUDs.

Driving safety and assistance systems are also key research areas for HUDs. Wu Y. et al. [25] evaluated the effectiveness of HUD warning systems in foggy conditions through simulator experiments. The results showed that HUDs can significantly reduce drivers' reaction times and thereby lower the risk of accidents. In terms of user experience and human-machine interaction (HMI), Morra L. et al. [23] proposed a method for evaluating user experience based on physiological signals and found that detailed road information helps to reduce driving stress and increase driving willingness.

The advancements in transparent energy storage and wearable technology have opened up new possibilities for the application of HUD in wearable devices. Liu T. et al. [22] demonstrated transparent thin-film supercapacitors, whose high power density and long cycle life laid the foundation for the application of HUD in wearable devices.

In the area of autonomous driving, HUD is employed to boost passengers' trust in and comprehension of the vehicle, Currano R. et al. [32] conducted research on the influence of HUD visualization awareness and perception. The findings indicated that HUD can remarkably enhance drivers' situational awareness.

The application of deep learning and computer vision technologies has enhanced the intelligence level of HUD systems. Borghi G. et al. [28] developed a driver head pose tracking system based on deep learning, significantly improving the accuracy of pose estimation.

5. Conclusion and Future Research Direction

Mathematics and statistics are widely applied in bibliometric analysis and academic achievement evaluation. This study focuses on the bibliometric analysis of research literature on HUDs in vehicles from 2015 to 2025, with data sourced from the Scopus database. The results show that both theoretical and applied research on vehicle HUDs have made significant progress. The number of published papers increased from 77 in 2015 to 97 in 2024. Researchers from China, Germany, and the United States have made outstanding contributions, with China and Germany ranking first and second in terms of paper output. The "Digest of Technical Papers – SID International Symposium" and the "Proceedings of SPIE – the International Society for Optical Engineering" series, as well as the "Lecture Notes in Computer Science" (including the "Lecture Notes in Artificial Intelligence" and "Lecture Notes in Bioinformatics" sub-series), are regarded as representative journals for HUD research. Gabbard JL (h-index=13), Burnett G (h-index=10), and Wang J (with 22 papers) are core authors. The main research themes are reflected by keywords such as "augmented reality", "virtual reality", "computer simulation", and "head-mounted displays". In recent years, the popularity of "head-up displays", "autonomous driving", and "augmented reality" has continued to rise.

In summary, the research on HUDs currently shows a significant trend of interdisciplinary collaboration and technological integration, covering a wide range of aspects including basic display technologies and advanced driver assistance systems. These scientific research advancements provide a solid theoretical and practical foundation for the extensive application of HUD technology in multiple industries such as automobiles, industry, and wearable devices. Looking ahead, with continuous technological iterations, HUDs are expected to play a more crucial role in optimizing user interaction experiences and enhancing system performance, creating greater value.

Acknowledgments

This work was supported by the Guangdong Province Philosophy and Social Science Planning Project [Grant No. GD23XSH28] and the 2025 Huizhou University Independent Innovation Capability Enhancement Plan Project [Grant No. HZU202530].

Reference

[1] Han, L. A review of research on head up displays (HUDs). 2025 [cited 2025; Available from: https://zhuanlan.zhihu.com/p/72504622.

[2] Zheng, Z. The Development Trend of HUDs as Seen from CES 2025. 2025 [cited 2025 20 Aprial, 2025]; Available from: https://www.smartautoclub.com/p/96618/.

[3] Betancur, J.A., et al., Research topics and implementation trends on automotive head-up display systems. International Journal on Interactive Design and Manufacturing (IJIDeM), 2018. 12(1): p. 199-214.

[4] Consulting, S.I., Analysis of Global Automotive HUD Market Size, Share, and COVID-19 Impact. 2024, Spherical Insights & Consulting. p. 200.

[5] Gabbard, J., G. Fitch, and H. Kim, Behind the Glass: Driver Challenges and Opportunities for AR Automotive

Applications. Proceedings of the IEEE, 2014. 102: p. 124-136.

[6] An, Z., et al., RETRACTED: Design and Performance of an Off-Axis Free-Form Mirror for a Rear Mounted Augmented-Reality Head-Up Display System (Retracted Article). IEEE PHOTONICS JOURNAL, 2021. 13(1).

[7] Ba, T., et al., Design of a Human-Computer Interaction Method for Intelligent Electric Vehicles. WORLD ELECTRIC VEHICLE JOURNAL, 2022. 13(10).

[8] Baghdadi, M., A. Ebert, and Acm, Approaching Intelligent In-vehicle Infotainment Systems through Fusion Visual-Speech Multimodal Interaction: A State-of-the-Art Review, in PROCEEDINGS OF EUROPEAN CONFERENCE ON COGNITIVE ERGONOMICS 2024, ECCE 2024. 2024.

[9] Abdi, L., F. Ben Abdallah, and A. Meddeb, In-Vehicle Augmented Reality Traffic Information System: A New Type of Communication Between Driver and Vehicle, in International Conference on Advanced Wireless Information and Communication Technologies (AWICT 2015). 2015. p. 242-249.

[10]Abdi, L. and A. Meddeb, Driver information system: a combination of augmented reality, deep learning and vehicular Ad-hoc networks. Multimedia Tools and Applications, 2018. 77(12): p. 14673-14703.

[11]Alkhalifah, E.S., Optimizing graphics for understanding real-scene using 3D image registration and tracking and mapping. Journal of Intelligent & Fuzzy Systems, 2024. 46(1): p. 2297-2309.

[12]Almquist, E., T. Mathis, and V.G. Duffy, Artificial Intelligence and Transportation - The Emergence of New Technologies and the Related Impacts on the Transportation of People and Packages, in Digital Human Modeling and Applications in Health, Safety, Ergonomics and Risk Management, DHM 2024, PT III. 2024. p. 165-181.

[13]Lyu, J., A.A. Zalay, and N.S.B.M. Salleh, A Bibliometric Approach to Multimodal Interaction Research Trends. Forest Chemicals Review, 2021: p. 1615-1636.

[14]Repanovici, A. Measuring the visibility of the university's scientific production using google scholar, Publish or Perish software and Scientometrics. in World library and information congress: 76th IFLA general conference and assembly. 2010. Science and Technology Libraries Gothenburg, Sweden.

[15]Tan, H., Zhao, J.H., and Wang, W., Research on the human-computer interface design of automobiles. Journal of automobile engineering, 2012. 2(5): p. 315-321.

[16]Mirhashemi, A., et al., Macro-level literature analysis on pedestrian safety: Bibliometric overview, conceptual frames, and trends. Accident Analysis & Prevention, 2022. 174: p. 106720.

[17]Chadegani, A.A., et al., A comparison between two main academic literature collections: Web of Science and Scopus databases. arXiv preprint arXiv:1305.0377, 2013.

[18]Elsevier. How Scopus Works. (December 2021; Available from: https://www.elsevier.com/solutions/scopus/how-scopus-works/content?dgcid=RN_ AGCM_Sourced_300005030.

[19]Agarwal, A., et al., Bibliometrics: tracking research impact by selecting the appropriate metrics. Asian journal of andrology, 2016. 18(2): p. 296-309.

[20]Wakunami, K., et al., Projection-type see-through holographic three-dimensional display. Nature Communications, 2016. 7.

[21]Marai, O.E., T. Taleb, and J. Song, Roads Infrastructure Digital Twin: A Step Toward Smarter Cities Realization. IEEE Network, 2021. 35(2): p. 136-143.

[22]Liu, T., et al., A Micromolding Method for Transparent and Flexible Thin-Film Supercapacitors and Hybrid Supercapacitors. Advanced Functional Materials, 2020. 30(46).

[23]Morra, L., et al., Building Trust in Autonomous Vehicles: Role of Virtual Reality Driving Simulators in HMI Design. IEEE Transactions on Vehicular Technology, 2019. 68(10): p. 9438-9450.

[24]Kim, H. and J.L. Gabbard, Assessing Distraction Potential of Augmented Reality Head-Up Displays for Vehicle Drivers. Human Factors, 2022. 64(5): p. 852-865.

[25]Wu, Y., et al., Effects of crash warning systems on rear-end crash avoidance behavior under fog conditions. Transportation Research Part C: Emerging Technologies, 2018. 95: p. 481-492.

[26]Wang, Z., et al., Driver Behavior Modeling Using Game Engine and Real Vehicle: A

Learning-Based Approach. IEEE Transactions on Intelligent Vehicles, 2020. 5(4): p. 738-749.

[27]Pavel, M.I., S.Y. Tan, and A. Abdullah, Vision-Based Autonomous Vehicle Systems Based on Deep Learning: A Systematic Literature Review. Applied Sciences (Switzerland), 2022. 12(14).

[28]Borghi, G., et al., Face-from-Depth for Head Pose Estimation on Depth Images. IEEE Transactions on Pattern Analysis and Machine Intelligence, 2020. 42(3): p. 596-609.

[29]Skirnewskaja, J. and T.D. Wilkinson, Automotive Holographic Head-Up Displays. Advanced Materials, 2022. 34(19).

[30]Moed, H.F., M. Luwel, and A.J. Nederhof, Towards research performance in the humanities. 2002.

[31]Tan, H., et al., User experience & usability of driving: A bibliometric analysis of 2000-2019. International Journal of Human–Computer Interaction, 2021. 37(4): p. 297-307.

[32]Currano, R., et al. Little road driving hud: Heads-up display complexity influences drivers' perceptions of automated vehicles. in Conference on Human Factors in Computing Systems - Proceedings. 2021. Association for Computing Machinery.

