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SCIENTIFIC REPORT

TECHNOLOGY TREND REPORT

Trends in Research and Development in Car Interiors and HMI as seen from Academic Citations

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The automobile is undergoing dramatic changes. It was conceived over 200 years ago, in 1769, and was initially propelled by steam engines. The gasoline engine was invented at the end of the 19th century, leading to the mass production of automobiles starting in the early 20th century. In recent years, manufacturers have diversified the automobile powertrain, offering hybrid, fuel-cell, and electric vehicles to reduce the environmental impact of automobiles. Furthermore, manufacturers are advancing technologies related to how vehicles send data to and receive it from the outside world, with intelligent transportation systems (ITS), vehicle-to-vehicle (V2V) communications, and connected cars. Using advanced driver-assistance systems (ADAS) and autonomous car technologies, automobile control is becoming increasingly independent of human intervention.

This transformation of the automobile could even have an impact on how users experience their familiar car interiors and how drivers interface with vehicles (collectively referred to as “interiors” below). Car interiors consist of numerous decorative elements, but it is likely that many of these elements will undergo a technological evolution. With this in mind, we analyzed car interiors from a technological perspective—using academic citations as a resource—to learn how research and development is being conducted and how this has changed over time.

When gathering academic citations on car interiors, we used Scopus, the publisher Elsevier's bibliographic database. Our search included automobile-related terms in article titles, abstracts, and keywords. In addition, we searched for co-occurrences of keywords, such as “interior” and “cabin,” with topics such as driver and human interfaces, interaction and communication, HMI systems, and ergonomics. We specifically targeted articles and conference papers that have been published in English since 2001. There were roughly 8,000 relevant articles.

MACRO TRENDS IN CAR INTERIORS

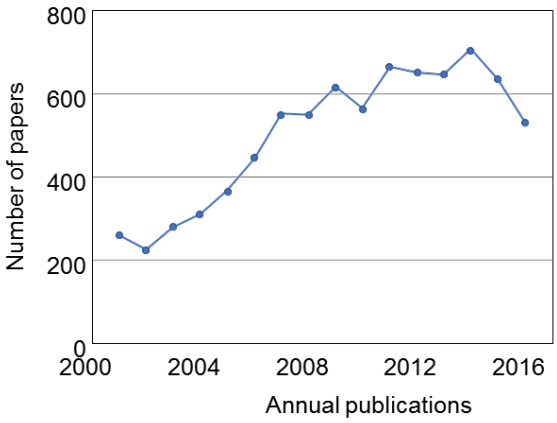


Figure 1 - Number of Car Interior-Related Articles

Figure 1 shows the number of car interior-related articles published annually. For this study, we gathered academic citations dating from 2001, but at that point, there were already more than 200 published articles on this topic. Since then, there has been a growth trend in the number of articles, but this number reached a saturation point in about 2011.

Figure 2 shows the top 10 countries by number of research papers. The number of papers published from 2001 to 2012 is indicated by the blue bars, while the number of papers published since then is indicated in red. Also, the figures in the parentheses are the ratio (%) of papers published since 2013.

By country, **the US has an overwhelming lead in the number of articles**, followed by Germany, China, Japan, and the UK. Per the ratio of recently published articles, it is clear that **China is rapidly increasing its number of publications**. South Korea and the UK are also seeing growth in this ratio. In terms of ranking by organization—arrived at using Scopus's tallying function—the organization with the most recent publications is Ford Motor (127 articles since 2001), followed by the Technical University of Munich (111 articles), General Motors (90 articles), Chalmers University of Technology (90 articles), and the University of Central Florida (77 articles). Although not surprising, considering our search topic is car interiors, it is unusual for private companies to make an appearance in the top ranks of the articles we gathered. In Japan, the University of Tokyo has the most articles, with 42.

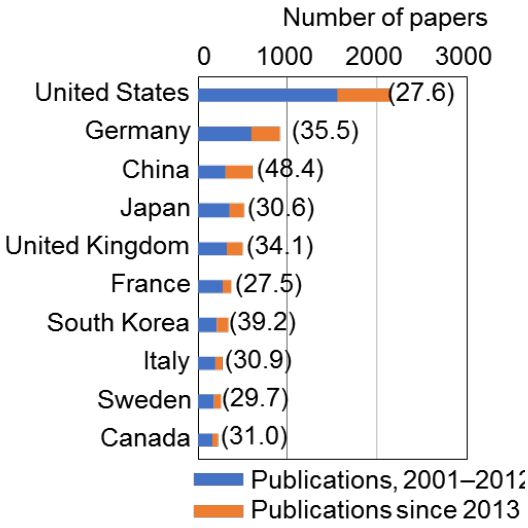


Figure 2 - Key Countries in Car Interior-Relate Research Publications

PANORAMIC VIEW ANALYSIS

Cluster Analysis of Car Interior-Related Articles

We performed a cluster analysis of the academic citations we gathered, in order to get a panoramic view of car interior-related research and development. We evaluated the feature quantity of documents gathered for our cluster analysis, which provides a visualization of this data based on the degree of similarity among documents. We used the titles and abstracts of the articles to evaluate their degree of similarity. The results of our cluster analysis are shown in Figure 3.

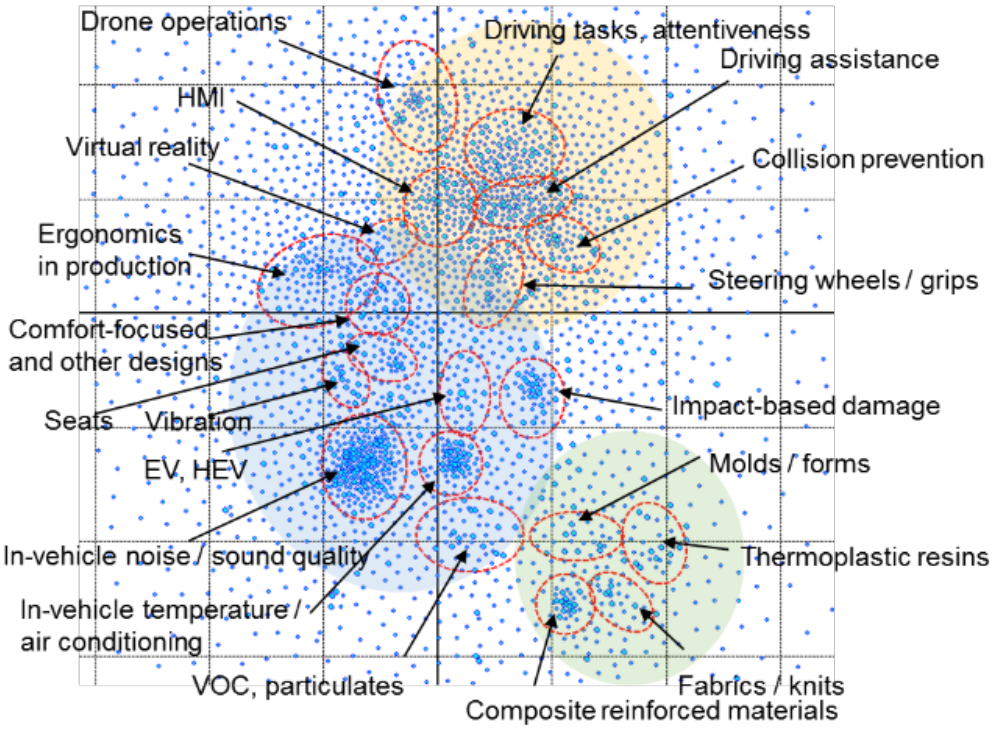


Figure 3 - Cluster Analysis Results for Car Interior-Related Articles

In Figure 3, concentrated clusters are circled in red dashed lines, and regions with multiple clusters are highlighted with colored shading. This makes it easier to distinguish among the major research fields.

The results of the cluster analysis are broadly divided among three key concentrated regions. Just above the horizontal axis of the cluster analysis, we find research focused on **human-machine interfaces** (HMI), which includes research on gesture-recognition interfaces and on classifying visuomotor workloads from simulated brain patterns. Research fields adjacent to HMI consist of research pertaining to **driving**

tasks and driver attentiveness, driver assistance and collision prevention, and steering wheel grips.

Below the horizontal axis, there are concentrations of research regarding **in-vehicle environments**, with a particularly high number of papers concerning in-vehicle noise, sound quality, and air conditioning. Additionally, we find research on volatile organic compounds (VOC) and particulates, vibration, and comfort-focused design in vehicles.

In the lower right corner of the analysis results, we see research for **interior materials**—including compound materials, fabrics, and knits—and thermoplastic resins, all aiming to improve the mechanical strength of these materials. There is also research regarding damage caused by collisions.

We created visualizations of how the car interior research trends have changed during this period—found in Figure 4—using our cluster analysis data. Within Figure 4, regions with the highest density of academic citations are shown in red, with the density decreasing, in order, from yellow to green and finally to blue. Furthermore, in order to facilitate annual comparisons, we standardized the maximum value of annual academic citations.

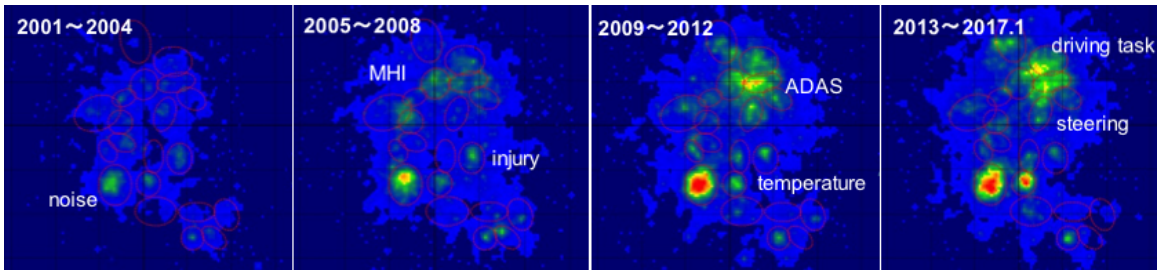


Figure 4 - Visualization of Research Trends using Cluster Analysis

Car interior-related research trends show that **most research was concerned with in-vehicle noise and acoustics** during the first half of the 2000s. Then, in the second half of the 2000s, researchers were actively looking at **HMI-focused interfaces**. Since 2009, there has been a further **increase in research related to ADAS and steering**. Research on in-vehicle environmental factors, such as noise and air conditioning, has continued to be published, while there has also been progress in terms of both comfort- and interface-centric research.

Among the research fields related to car interiors, over the years, there has been a clear qualitative shift in the fields of noise and acoustics, which have continued to see active inquiry. Therefore, we reviewed the differences in keyword occurrence frequencies before 2012 and since 2012. As a result, we found rapid, successive increases in keywords such as “electric vehicle”; “noise, vibration, and harshness” (NVH); and “active noise control” (ANC) since 2013, indicating that **research is being conducted due to the diversification of powertrains** and the need for comfortable interior spaces.

Similarly, in the region for air conditioning, we confirmed a keyword shift, with increasing precedence for keywords such as “fuel consumption,” “electric vehicle,” and “solar radiation.” This demonstrates that, in addition to responses to changing powertrains, **research is being conducted on controlling energy consumption** caused by air conditioning.

Looking toward the keyword shift in the HMI region, recent years have seen rises in keywords such as “gesture recognition,” “mobile device,” and “graphical user interface.” **It is possible that the spread of smartphones could be bringing about changes to automobile HMIs**.

Research Fields for Key Automobile Manufacturers

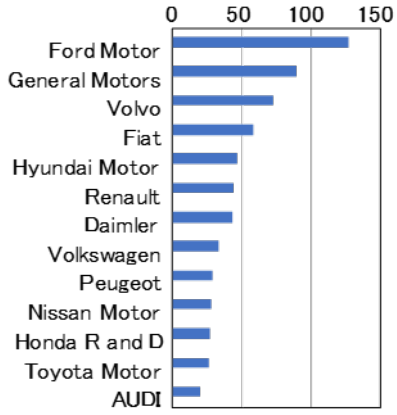


Figure 5 shows the key automobile manufacturers that are publishing articles related to car interiors, while Figure 6 contains these research fields.

From the perspective of the number of academic citations, the key automobile manufacturers are led by two US companies: Ford and GM. They are followed by European manufacturers, including Volvo, Fiat, and Renault. In Asia, Hyundai Motors is ranked higher than Japanese companies such as Nissan, Honda R&D, and Toyota.

Figure 5 - Key Automobile Manufacturers in Car Interior Research

In terms of research fields, automobile manufacturers’ articles are characterized by less research in materials (the bottom right corner of the cluster analysis results) and **more research in comfort-related topics, such as noise and air conditioning**. They are also active in research pertaining to machine interfaces. An overview of the research fields for the top three companies is as follows:

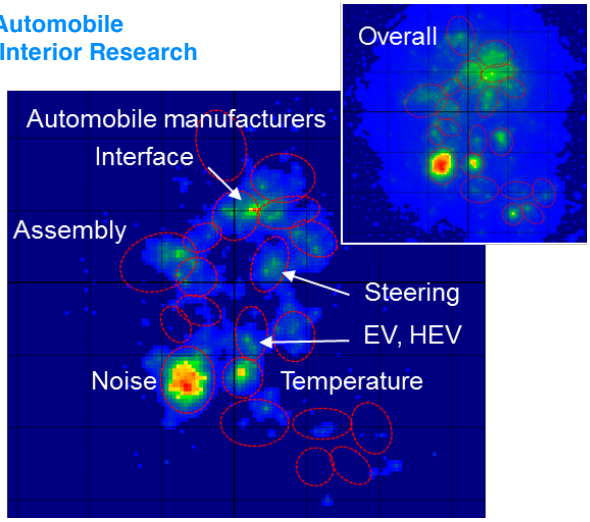


Figure 6 - Research Fields for Automobile Manufacutrers

Ford Motor

Ford has the most published articles among the automobile manufacturers. Its research is mostly concentrated in the regions of **noise and sound quality and of damage caused by collisions**.

GM

Like Ford, GM's research fields are mostly related to **noise, sound quality, and air conditioning**. It also conducts research related to **steering**.

Volvo

Unlike the top two companies, Volvo's research is **mostly concerned with HMI and collision warnings**. Its HMI research consists of many joint publications with companies such as Fiat, BMW, and Robert Bosch. We found keywords such as "Adaptive Integrated Driver Vehicle Interface" (AIDE) in Volvo's HMI regions, which are a part of the EU's Sixth Framework Programme (FP6). This project aimed to promote research and development in advanced driver assistance systems among multiple companies and research institutions.

Transformations, Research and Development in Automobiles

In order to clarify the connection between transformations arising in automobiles and interiors, we looked at the following keywords:

- Electric vehicle
- Infotainment / entertainment
- Augmented / virtual reality
- Autonomous vehicle / drive

Figure 7 shows the change over time in the number of articles in which each keyword co-occurs, from among the total corpus of articles we gathered for this study.

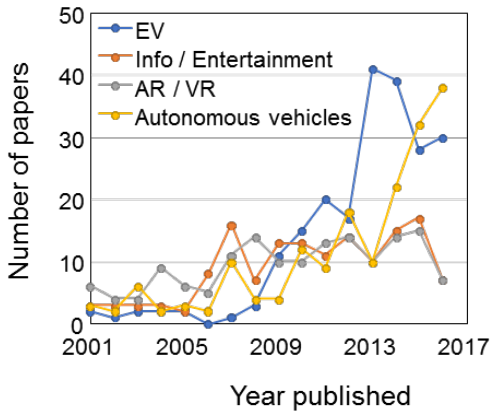


Figure 7 - Co-Occurences Over Time of Each Keyword in Articles

All the keywords tended to increase, but **"autonomous driving" has demonstrated a remarkably rapid increase since 2013**. The number of articles containing "EV" has been on the rise from slightly earlier, since 2009. The number of hits for "infotainment / entertainment" and "AR / VR" are gradually increasing. We explain the research that includes each of these keywords below:

Electric vehicle

The research concerned with EV (including HEV and PHEV)—a powertrain likely to grow in popularity—is shown in Fig. 8.

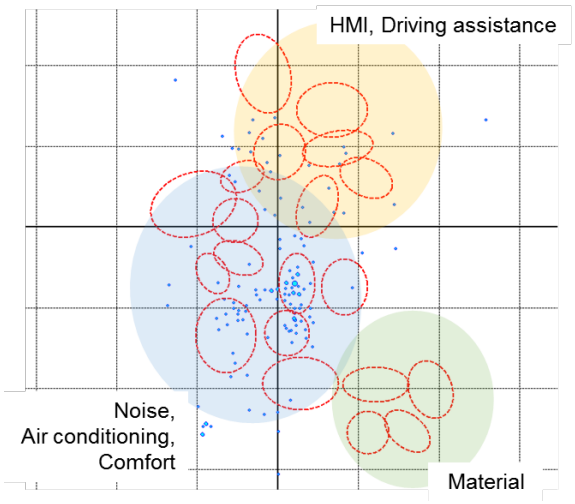


Figure 5 – Research on EV (including HEV and PHEV)

EV-related research that concerns car interiors is frequently found in research fields related to comfort, such as air conditioning and noise. Noise-related research includes topics such as sound design and interior noise. This region includes research regarding the changes in noise and vibration contributed by EVs, as well as the need to measure sound inside and outside vehicles to respond to improvements in the silent operation that coincides with the shift to EVs. In the research pertaining to air conditioning, we find co-occurrences of keywords such as “drive range” and “electric power.” This research is related to reducing the waste heat caused by EVs and to the influence air conditioning has on power consumption.

Infotainment / entertainment

The fusion of automobiles and telecommunications technology (the computerization of cars) can be linked to the increase in the volume of data found within vehicles. Figure 9 shows a visualization of the co-occurrence of related keywords and interiors in our research corpus.

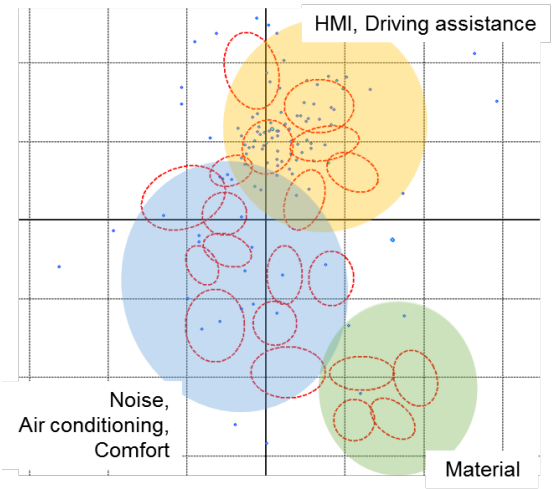


Figure 6 - Research on Infotainment/Entertainment

Related articles are particularly concentrated in research fields related to HMI, and they can also be found in research fields for driving tasks, attentiveness, and driver assistance.

Keywords co-occurring with HMI include “mobile device” and “driver distraction.” This research includes interactions using gestures via in-vehicle tablet PCs, investigations into future information systems and new in-vehicle tasks due to the spread of mobile devices, and guidelines to prevent driver distraction caused by the addition of new in-vehicle functions.

Augmented / virtual reality

Technologies expected to become increasingly important for interfacing with humans are augmented and virtual realities. Figure 10 shows research in which these keywords co-occur with car interiors.

AR- / VR-related research often appears in regions related to HMI and regions where HMI and comfort meet. The prominent keywords found in this research include “HMI,” “virtual object,” and “assembly.” Specifically, we find research related to responding to the diversification of information and to evaluating these responses. For instance, topics include heads-up displays for vehicle-mounted AR systems and composites of information using these displays. Additionally, there is research concerned with applications during the design and development of such systems, including design development programs and simulators using AR / VR.

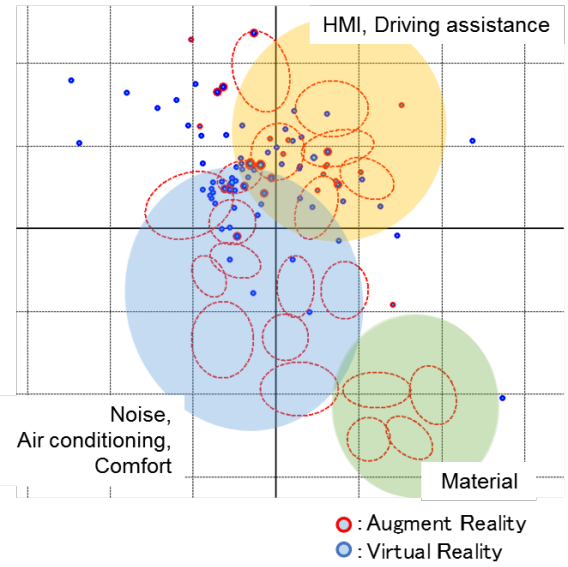
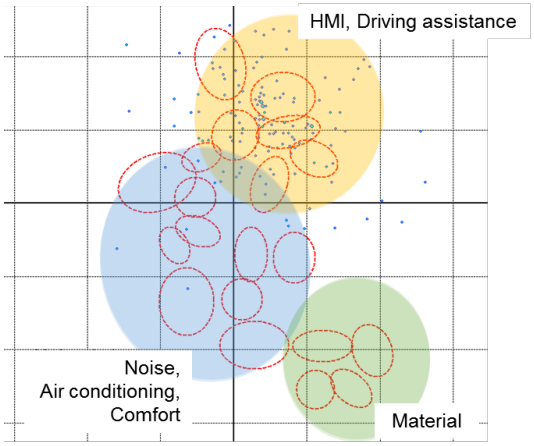


Figure 7 - Research on AR / VR

Autonomous vehicle / drive

Currently, automobiles are being equipped with driver assistance systems, which will eventually lead to autonomously driven automobiles. Figure 11 shows research fields in which “autonomous driving” co-occurs with “car interiors.”



Research related to autonomous driving is concentrated in regions for HMI and driver assistance. Primary keywords include “HMI,” “drive task,” and “situation awareness.”

The “HMI” keyword is found in research in HMI designs for autonomously driven vehicles (including phases when transitioning from autonomous to manual driving) and driving status notifications for drivers during autonomous driving. We also found examples of research related to the efficacy of auditory displays for warnings and the like when the driver is resting or doing other work during autonomous

Figure 8 - Research on Autonomous Vehicle / Drive

driving. Furthermore, there were examples of inquiries into problems such as how pedestrians and bicyclists will interact with autonomous vehicles when a human driver is not present. Until the realization of completely autonomous driving, researchers will likely need to work out what driving tasks drivers will be responsible for, as well as the interfaces and systems designed to respond to these tasks.

CONCLUSIONS

This study looked at research and development trends related to car interiors, including interfaces among HMI systems, drivers, and vehicles. In addition to providing a panoramic overview of this topic from the academic citations we gathered, we gave an outline of this research, including trends among automobile manufacturers and several of the keywords related to automobile transformations.

Research trends in car interiors show a continued interest in **research related to in-vehicle noise, sound quality, and air conditioning, as well as an increasing interest in fields such as HMI**. These fields are particularly prominent in the articles published by European and American automobile manufacturers, indicating their strong interest in these fields. At the same time, automobile manufacturers are not key players in materials research.

We also touched on car interior-related research from the perspectives of EVs and the computerization of automobiles, AR / VR, and autonomous driving.

EVs co-occur with research related to comfort in automobiles, covering topics such as noise and air conditioning. This research could aim to solve problems that originate in the declining use of the internal combustion engine, such as the change in sound sources in EVs, the reduction of waste heat, and the power consumption of air conditioning. In terms of the computerization of automobiles and AR / VR, one issue is the question of how vehicles will efficiently display large volumes of information to drivers. Research on autonomous driving is concerned with warning drivers during autonomous driving and communicating the driving status.

The perspectives demonstrated here remain but a tiny portion of future phenomena we will see in the field of car interiors. If we think of the different elements of car interiors, such as the steering wheel, the dashboard, and the seats, we can imagine that each element will have its own issues.

For Japan, the automobile industry is a core industry, and it will compete with American and European companies in the future. In such an environment, the development of interiors and HMI systems to respond to technological innovation in automobiles will likely become a crucial selling point. From the perspective of academic citations, Japanese public research institutions and automobile manufacturers are not as active in these fields as other countries. We expect that systems in the form of public investments

or consortiums, like those seen in Europe, could invigorate future research and development in Japan.

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After serving as a researcher at the Research Development Corporation of Japan and as lead researcher at Mitsubishi Research Institute, Inc., he has been in his current position since 2008. Fields of expertise: Analysis of cutting-edge science and technology fields such as nanotechnology and nanomaterials; research and analysis of international science and technology.