Journal of Electronic Research and Application, 2025, Volume 9, Issue 4
http://ojs.bbwpublisher.com/index.php/JERA
ISSN Online: 2208-3510
ISSN Print: 2208-3502

Application and Innovation of Automotive Electronics Structural Design in Center Console Instruments

Peijie Jia*

Shenzhen Maximatech Automotive Electronics Co., Ltd., Shenzhen 518000, Guangdong, China

**Author to whom correspondence should be addressed.*

Abstract: This paper introduces the key design aspects of automotive center console instrument systems, including hardware architecture, ergonomics, antenna layout, etc. It elaborates on the application and advantages of various advanced technologies, such as 3D printing and dual-color injection molding. Additionally, it discusses advancements in structural design, as well as future challenges and the trend of multidisciplinary collaborative innovation.

Keywords: Automotive center console instrument; Structural design; Technology application

Online publication: August 7, 2025

1. Introduction

With the rapid development of the automotive industry, the structural design of automotive electronic products is highly valued in the field of central control instruments. The "Development Plan for New Energy Vehicle Industry (2021–2035)" released in 2020 emphasizes the development direction of intelligent and networked automobiles, which puts higher requirements on the structural design of central control instruments. The hardware architecture of the central control instrument includes key human-machine interaction components such as display modules and control units, and its design must comply with ergonomics. Meanwhile, the layout of GPS/Beidou dual-mode antennas and the optimization of panoramic imaging system structure are also crucial. In addition, the integration of thermal management systems, integrated and modular design methods, and reliability verification are all key contents of the structural design of automotive electronic products. Research and development in these areas will promote continuous progress in the field of automotive central control instruments.

2. Fundamentals of structural design for automotive central control instruments

2.1. Composition of the central control instrument system architecture

The hardware architecture of the in-vehicle central control system includes multiple key components [1]. The display module is an important component responsible for visualizing information, and its performance and design directly affect the user's ability to obtain information. The control unit plays a core role in computation and control, processing various input signals and coordinating the work of various components. The physical integration method of the human-computer interaction interface is also crucial, as it determines the interaction experience between users and the central control system. A reasonable integration method should consider the convenience and comfort of operation, such as button layout, touch area design, etc. These parts work together to form the architecture of the central control instrument system, providing a foundation for the normal operation and functional implementation of the car's central control instrument.

2.2. Application of ergonomics

Ergonomics is crucial in the structural design of automotive control instruments [2]. The tilt angle of the control panel should take into account both the driver's line of sight and operational convenience to reduce visual fatigue and misoperation. The appropriate angle allows the driver to clearly see panel information and naturally extend their arms while sitting in a normal driving position. The key layout should be based on commonly used functions and operating frequencies, placing important and frequently used keys in easily accessible areas, while considering the spacing between keys to avoid accidental presses. In terms of touch feedback, appropriate tactile and auditory feedback should be provided to allow the driver to confirm that the operation has been received. These designs should fully consider human body size, sensory characteristics, and operating habits in order to enhance the usability and safety of the central control instrument.

3. Innovation in navigation and camera system structure

3.1. Integration of multimodal navigation system

The GPS/Beidou dual-mode antenna layout is a key component of multimodal navigation system integration. A reasonable layout can improve signal reception quality and enhance navigation accuracy. By optimizing the design of antenna position, direction, and surrounding environment, signal obstruction and interference can be reduced [3]. The design of anti-electromagnetic interference structures is equally important. In the automotive electronic environment, multiple electronic devices work simultaneously, and electromagnetic interference is complex. The use of shielding materials and a reasonable circuit layout can effectively reduce the impact of electromagnetic interference on navigation systems and ensure the stability of signal transmission. Vibration buffering design is also indispensable. During the driving process of a car, vibrations may occur, which may affect the normal operation of navigation devices. By designing appropriate shock-absorbing structures, such as using elastic materials or shock absorbers, the internal components of the navigation system can be protected, improving its reliability and service life.

3.2. Optimization of panoramic imaging system structure

In the optimization of the panoramic imaging system structure, the installation angle of the fisheye lens is crucial. A reasonable angle can ensure the acquisition of comprehensive and accurate image information, avoiding visual blind spots. The determination of its angle requires comprehensive consideration of factors such as the vehicle's appearance, usage scenarios, and coordination with other components [4]. The design of waterproof and dustproof structures is the key to ensuring the stable operation of the system. The driving environment of automobiles is complex and varied, and good waterproof and dustproof performance can prevent water vapor and dust from entering the lens and internal circuits, extending the service life of the equipment. The physical channel design of the image transmission harness cannot be ignored. Reasonable channel planning can reduce signal interference, ensure the quality and stability of image transmission, and provide strong support for the efficient operation of panoramic imaging systems.

4. Integrated structural design method

4.1. Modular design strategy

4.1.1. Integration of thermal management system

In the structural design of automotive electronic products, the integration of thermal management systems is crucial. The layout of the heat dissipation duct and electronic components needs to be designed in coordination to ensure that the electronic components work in a suitable temperature environment. Reasonably plan the layout of electronic components to ensure proper density and avoid local overheating. At the same time, design heat dissipation ducts that match the heating characteristics and layout of the components. The direction and size of the air duct, as well as the position of the air outlet and air inlet, should be carefully considered to achieve efficient heat transfer and dissipation. Through this collaborative design method, the efficiency of thermal management systems can be improved, the reliability and stability of automotive electronic products in central control instruments can be enhanced, and strong guarantees can be provided for the performance improvement of automotive electronic products [5].

4.1.2. Topology optimization of wiring harness

In the structural design of automotive electronic products, integrated structural design methods, modular design strategies, and wire harness topology optimization are crucial for the central control instrument part. In terms of integrated structural design, it is necessary to comprehensively consider the functions and connection relationships of each component to achieve a compact and efficient overall structure. The modular design strategy emphasizes the reasonable division of different functional modules for easy production, maintenance, and upgrading. The key to optimizing the topology of wiring harnesses is to study the spatial planning of the hierarchical routing structure of CAN bus and power lines. Reasonable planning of its spatial orientation can reduce electromagnetic interference and improve the stability and reliability of signal transmission [6]. Through the comprehensive application of these design methods and strategies, the performance and quality of electronic product structures for automotive control instruments can be improved, meeting the growing demands of the automotive industry.

4.2. Reliability verification system

4.2.1. Vibration durability test

In the vibration durability testing of the reliability verification system, it is crucial to construct a mechanical structure reinforcement verification scheme that includes road spectrum analysis. By accurately analyzing the actual road spectrum, the vibration characteristics of vehicles under different road conditions can be obtained. Applying these characteristics to the simulation of the testing environment can more accurately reflect the actual operating conditions of automotive electronic products in the central control instrument panel. By utilizing advanced testing equipment and technology, the mechanical structure of the central control instrument is subjected to long-term vibration durability testing to observe its performance at different vibration frequencies and amplitudes, ensuring that the structural design can withstand expected vibration stresses, thereby improving the reliability and stability of the product and providing strong structural design guarantees for the application of automotive electronic products in central control instruments [7].

4.2.2. Environmental adaptability design

In terms of environmental adaptability in the design of central control instrument structures for automotive electronic products, temperature cycling and salt spray testing are crucial for material selection. Strict material selection standards need to be established for different working environment temperature ranges and possible salt spray corrosion situations. It is necessary to consider the physical stability of materials under alternating high and low temperature environments, such as thermal expansion coefficient, strength, etc., to ensure that deformation, cracking, and other problems will not occur due to temperature changes, which will affect product performance and reliability [8]. At the same time, for salt spray environments, materials should have good corrosion resistance to prevent faults such as circuit short circuits and component damage caused by corrosion. By establishing scientifically reasonable material selection standards, the adaptability and service life of central control instruments in automotive electronic products can be effectively improved in complex environments.

5. Application and development of innovative technologies

5.1. Application of new materials

5.1.1. Magnesium aluminum alloy frame

Magnesium aluminum alloy, as a new type of material, has significant advantages in the design of automotive central control dashboard frames. It has a high strength-to-weight ratio, which can effectively reduce the weight of the dashboard while ensuring structural strength, in line with the development trend of automotive lightweighting [9]. The good plasticity of this material makes it easy to process into complex shapes, meeting the unique design requirements of the central control panel skeleton. In addition, magnesium aluminum alloy also has good thermal conductivity and electromagnetic shielding performance, which can effectively solve the heat dissipation and electromagnetic interference problems generated by automotive electronic products during operation. In practical applications, topology optimization design methods can further improve the performance of magnesium aluminum alloy frames, minimizing material usage, reducing costs, and improving production efficiency while meeting mechanical performance requirements.

5.1.2. Composite plastic injection molding

The dual color injection molding process is an advanced injection molding technology that has important applications in the manufacturing of complex curved panels for automotive control instruments. It can achieve complex appearance effects and functional requirements by successively injecting two plastics of different colors or materials into the same mold. This technique can improve the aesthetics of the panel, for example, by enhancing the visual hierarchy through the combination of different colors. At the same time, it can also enhance the functionality of the panel, such as utilizing the characteristics of different materials to achieve better wear resistance, corrosion resistance, etc. In practical applications, the two-color injection molding process requires precise control of injection molding parameters such as temperature, pressure, and time to ensure that the two plastics can be well combined to form high-quality products. The application of this technology provides an efficient and reliable solution for the manufacturing of complex curved panels in automotive control instruments, promoting innovation and development in the structural design of automotive electronic products [10].

5.2. Advanced manufacturing technology

5.2.1. 3D printing technology

3D printing technology is of great strategic significance in the application of central control instruments within the structural design realm of modern automotive electronic products. It empowers engineers to achieve rapid, high-fidelity prototyping of intricate, highly irregular structural components that previously challenged conventional subtractive or injection-molding workflows. Taking, for instance, the ergonomically sculpted bezels, lattice-ventilated housings, and snap-fit connector shrouds found in contemporary central control instrument clusters, traditional manufacturing processes often struggle to meet stringent tolerances, undercut geometries, and multi-axis curvature demands without costly secondary machining or complex tooling. In contrast, additive manufacturing—whether executed through selective laser sintering, multi-jet fusion, or stereolithography—constructs the exact designed shape by depositing or curing material layer by layer under computer-guided precision. This capability not only compresses production lead times and shortens the overall research and development cycle from weeks to days, but also reduces capital expenditure on hard tooling, thereby lowering unit costs for both prototype and low-to-medium volume production runs. Concurrently, 3D printing offers an expansive palette of engineering-grade materials: lightweight photopolymers for aesthetic casings, carbon-fiber-reinforced nylons for impact-resistant brackets, or corrosion-resistant aluminium alloys for heat-dissipating shields. Such material versatility allows designers to balance mechanical strength, thermal performance, surface finish, and electromagnetic shielding requirements specific to the central control instrument. Consequently, additive manufacturing delivers agile iteration loops, functional integration possibilities, and supply-chain resilience, providing strong, future-ready support for continuous innovation in the structural design of automotive electronic products.

5.2.2. Nanoimprint technology

Nanoimprint lithography has emerged as a pivotal enabler for advanced surface texture treatment of automotive control instrument panels, where nanoscale precision directly translates into elevated user experience and product differentiation. By leveraging precisely engineered molds, the technology transfers sub-micron patterns onto polymeric or glass substrates with exceptional fidelity, granting designers deterministic command over micro- and nano-topography. To enhance touch sensitivity, nanoimprint creates bespoke ridge, pillar, or moth-eye textures whose periodicity and aspect ratio are tuned to modify both optical haze and dielectric constant at the interface. These engineered micro-nano structures optimize the fringing electric field of projected capacitive arrays, strengthen capacitive coupling between finger and sensor, and attenuate parasitic noise arising from moisture, EMI, or temperature drift; together, these effects yield markedly higher touch accuracy and faster response times even when drivers wear gloves. In parallel, nanoimprint retains the classic merits of a high-throughput, low-cost roll-to-roll or step-and-flash process whose cycle times rival conventional screen printing, making it economically attractive for high-volume automotive production lines. Robust silicone or nickel working shims ensure repeatable pattern transfer across polycarbonate, PMMA, or chemically strengthened glass carriers, guaranteeing cross-panel dimensional consistency and statistical process control. Consequently, nanoimprint not only unlocks new aesthetic possibilities—matte metallic finishes, anti-glare surfaces, and hidden-until-lit icons—but also delivers functional integration that brings continuous innovation and systematic optimization to the structural design of automotive electronic products.

5.3. Intelligent structural innovation

5.3.1. Adaptive display mechanism

The screen-angle automatic adjustment system driven by an electric push rod represents a pivotal innovation within the adaptive display mechanism of modern automotive interiors. Leveraging the precise, low-backlash linear driving capability of a high-torque electric push rod, the system continuously modulates the inclination, tilt, and swivel of the central information display in real time. Ambient light sensors, near-infrared driver-tracking cameras, and ultrasonic seat-position sensors feed multi-modal data streams to a dedicated central control ECU running Kalman-filtered fusion algorithms. After predictive analysis of glare sources, solar azimuth, and the driver's eye-box coordinates, the ECU computes the optimal screen orientation that simultaneously minimizes reflections and maximizes legibility. A closed-loop PID controller then commands the electric push rod to execute sub-degree angular corrections within 300 milliseconds, while Hall-effect encoders confirm positional accuracy to ±0.1°. This innovation not only elevates ergonomic comfort and visibility during dynamic driving conditions—such as urban dusk, highway tunnels, or off-road articulations—but also advances the overall intelligence and user-centricity of automotive electronic product architectures. Furthermore, the modular rail-and-bracket interface ensures robust mechanical compatibility across diverse dashboard geometries, seat heights, and steering-column positions, granting OEMs scalable deployment across A-segment to full-size SUVs. Consequently, the system delivers an adaptable, future-proof solution that provides new technical support for the continuous evolution of automotive central control instruments.

5.3.2. Deformable interactive interface

In the rapidly evolving field of automotive central control instruments, the pursuit of innovative deformable interactive interfaces driven by intelligent structures has emerged as a pivotal development direction, promising to redefine the human-machine relationship within the cockpit. Among the most compelling embodiments of this trend, the dynamic conversion mechanism that seamlessly alternates between physical buttons and capacitive touch screens has garnered intense industry attention. This holistic design philosophy seeks to harmoniously integrate the unmistakable tactile feedback and muscle-memory advantages of conventional pushbuttons with the limitless configurability and aesthetic minimalism offered by modern multi-touch displays. Through a sophisticated marriage of origami-inspired kinematic linkages, micro-electromechanical actuators, and adaptive electronic control algorithms, discrete clusters of high-durability keys can be electromagnetically elevated above the glass plane when driving conditions demand eyes-free operation, then silently retract flush into the surface when infotainment or navigation tasks dominate, thereby reclaiming the entire screen real estate for rich gestural interaction. Such morphological agility not only elevates the convenience, comfort, and perceived quality perceived by the driver and passengers, but also empowers the vehicle to contextually modulate its interface modality in real time. For instance, mission-critical functions such as HVAC defrost or hazard lights remain instantly accessible via robust, pop-up buttons at highway speeds, whereas parked leisure scenarios unlock a full-span touch canvas for immersive media browsing, gaming, or personalized ambient lighting orchestration. By embedding force-sensing films, localized haptic actuators, and predictive user-intent models, the system can even pre-shape the interface before conscious interaction, thereby minimizing glance time and cognitive load. Ultimately, this convergent approach offers fresh paradigms and systematic methodologies for the structural design of automotive electronic products, catalyzing safer, more intuitive, and emotionally engaging cockpit experiences while simultaneously simplifying supply chains through modular, software-defined hardware layers.

6. Conclusion

Significant progress has been made in the structural design of automotive electronic products in the field of central control instruments. In terms of integration, a high degree of integration of multiple functional modules has been achieved, improving space utilization and system performance. In terms of intelligence, it has stronger information processing and interaction capabilities, meeting the growing demand for intelligence from users. At the same time, there have been technological breakthroughs in reliability, ensuring the stable operation of products in complex environments.

Looking ahead, emerging interactive modalities such as augmented-reality head-up displays and holographic projection layers will introduce unprecedented challenges to structural design. Engineers must rethink dashboard topology, optical paths, and thermal budgets to seamlessly accommodate waveguides, micro-LED arrays, and volumetric light engines, thereby delivering wider fields of view, minimized latency, and richer depth cues without compromising crash safety. Multidisciplinary collaborative innovation has become the key to the development of the next generation of intelligent cockpits. The deep integration of mechanics, electronics, optics, human factors, and advanced materials will inject new impetus into the application and innovation of structural design of automotive electronic products in central control instruments, continuously propelling the industry toward safer, more immersive, and intuitively connected user experiences.

Disclosure statement

The author declares no conflict of interest.

References

[1] Zaman N, 2015, Automotive Electronics Design Fundamentals, Springer, Cham.

[2] Ribbens W, 2017, Understanding Automotive Electronics: An Engineering Perspective, Butterworth-Heinemann.

[3] Soares FTF, 2016, Automotive Central Console Interface Design, dissertation, Instituto Politecnico do Cavado e do Ave (Portugal).

[4] Fleming B, 2015, Advances in Automotive Electronics. IEEE Vehicular Technology Magazine, 10(4): 4–96.

[5] Hylving L, Schultze U, 2013, Evolving the Modular Layered Architecture in Digital Innovation: The Case of the Car's Instrument Cluster, ICIS, 34: 1–17.

[6] Elmarakbi A, 2013, Advanced Composite Materials for Automotive Applications: Structural Integrity and Crashworthiness, John Wiley & Sons.

[7] Luo AA, 2013, Magnesium Casting Technology for Structural Applications. Journal of Magnesium and Alloys, 1(1): 2–22.

[8] Viswanadhapalli B, Bupesh Raja VK, 2019, Application of Magnesium Alloys in Automotive Industry-A Review, International Conference on Emerging Current Trends in Computing and Expert Technology, Springer International Publishing, Cham, 519–531.

[9] Blomeyer D, Schulte-Gehrmann AL, 2019, Surface Innovations for Interiors of Future Vehicles. ATZ Worldwide, 121(6): 48–51.

[10] Song H, 2021, The Necessity Analysis of Car Center Console in Car Based on Virtual Technology, 2021 International Conference on Computer, Internet of Things and Control Engineering (CITCE), IEEE, 171–176.

Publisher's note

Bio-Byword Scientific Publishing remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.