Embroidery-Enabled Smart Textiles for Energy-Efficient Automotive Interiors

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Abstract

Thermal management has become a key challenge in automotive interior design, driven by the increasing demand for passenger comfort, energy efficiency and sustainable mobility. In electric vehicles, conventional cabin heating systems significantly increase energy consumption, reducing driving range. Consequently, localized heating strategies based on the thermal bubble concept have emerged as an effective approach to deliver thermal comfort directly to vehicle occupants while minimizing unnecessary energy use.
This work presents the development of embroidery-enabled smart textiles incorporating integrated heating systems for automotive interior applications. The proposed solution combines multilayer textile structures with conductive yarns seamlessly integrated by embroidery technology, enabling the direct incorporation of heating elements into textile substrates. Compared with conventional manufacturing methods, embroidery provides high design flexibility, precise positioning of conductive yarns, excellent adaptability to complex geometries and the possibility of creating customized heating patterns with homogeneous heat distribution. Moreover, this technology preserves the flexibility, softness and aesthetic quality of the textile while enabling lightweight, durable and multifunctional heating systems suitable for next-generation automotive interiors.

The developed smart textile systems were designed to fulfil the demanding requirements of automotive applications, including thermal performance, passenger comfort, durability and compliance with automotive specifications. Sustainability was addressed through the selection of recycled materials and mono-material design strategies, supporting circularity and reducing environmental impact. The viability of the proposed solution was demonstrated through its integration into different automotive interior components and the evaluation of its thermal performance in a climatic chamber under representative operating conditions.

The proposed smart textile heating system represents a promising solution for the development of energy-efficient automotive interiors by combining advanced textile engineering, smart manufacturing and sustainable design principles. Its ability to provide localized thermal comfort while maintaining flexibility, functionality and aesthetic quality highlights the potential of embroidery technology as a key enabler for future intelligent automotive interior

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components.

This research was carried out within the framework of the GreenAuto (No. C644867037-00000013), Project No. 54, WP2 – New Concepts for Automotive Interiors, PPS2 – Intelligent, Functionalized and Digital Materials, funded by the Recovery and Resilience Plan (RRP) under the NextGenerationEU programme of the European Union

Keywords: Smart textiles, Multilayered textiles, Embroidery technology, Thermal management, Automotive interiors, Energy efficiency.