



# Development and Application of Intelligent Packaging Design under the Background of Artificial Intelligence

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**ABSTRACT.** Digital technologies such as artificial intelligence and big data are transforming traditional industries, including intelligent packaging design. As the manufacturing industry develops, consumer expectations for packaging are increasing, presenting challenges for technological innovation and integrated development of intelligent packaging. This paper explores these challenges and proposes strategies for organic integration of technology, environmental protection, and aesthetics in intelligent packaging design. These strategies include strengthening technological innovation, improving environmental performance, emphasizing aesthetic design, and guiding consumer consumption concepts to improve the added value and market competitiveness of packaging.

**Keywords:** Artificial intelligence, Intelligent packaging, Packaging design, Value system.

## 1 Introduction

The ever-evolving landscape of consumer demands and technological advancements has rendered traditional product packaging insufficient to meet consumer needs' growing complexity. To address this challenge, intelligent packaging design has emerged as a rapidly developing area of focus. By incorporating cutting-edge scientific materials, data monitoring, and other advanced technologies and functionalities, intelligent packaging design seeks to revolutionize traditional packaging through digitization and intelligentization, ultimately enhancing the overall value and experience of product packaging. This interdisciplinary approach has the potential to transform the packaging industry, offering innovative solutions that will cater to the needs of an ever-evolving consumer base. The main objective of this article is to initiate a discussion on the development trends and potential applications of intelligent packaging, using artificial intelligence as a starting point. By analyzing the functional hierarchy and constituent elements of intelligent packaging, this article aims to offer valuable insights that can be used as a reference to promote its further development. From the perspective of packaging design development, it can be divided into extensive, formative, and developmental periods. Packaging and technology were relatively simple in

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the developmental phase, often limited to essential information display functionality. However, packaging took on a more diverse interaction form during the formative period, with closer integration of packaging and technology, resulting in higher added value. During the developmental period, packaging demonstrated intelligent and adaptive features, leading to deep learning systems with the extension and expansion of artificial intelligence technology, enabling genuine communication between packaging and humans. In recent years, the market has seen a proliferation of intelligent packaging design products with the goal of intelligentization. Although these products offer certain advantages, they have indirectly led to problems such as high product consumption costs, excessive consumption of environmental resources, and difficulty in recycling packaging waste [1]. To effectively solve these problems, we need to recognize development misconceptions and search for new value-pursuit goals. We can only achieve sustainable packaging design development and better meet consumer needs.

## **2 The integration of ai and intelligent packaging**

The increasing awareness of global environmental protection has promoted the transformation of packaging materials. Meanwhile, with the continuous development of artificial intelligence (AI) and its profound impact on the design field, it has become possible to assist designers in achieving astonishing results. Applying AI to the design of intelligent packaging and other structures can shorten manufacturing time and improve traditional design methods, according to Milazzo et al. AI has also changed the traditional way of selling products and packaging forms, leading to the widespread attention and application of intelligent packaging design[2]. This has resulted in a closer connection between consumers and intelligent packaging, with packaging becoming more intelligent and emotionally integrated, becoming a "living product."

### **2.1 The value manifestation of intelligent packaging design**

The continuous development of new technologies has opened up possibilities for intelligent packaging design, combining aesthetics, functionality, and interactivity to provide a better consumption and usage experience. Intelligent packaging design has three main values, which are reflected in the increased technological content of the product, enhanced safety and traceability, and improved brand image and market competitiveness. With the integration of new technologies like artificial intelligence, machine learning, and the Internet of Things, intelligent packaging design has become an important trend in the future packaging industry. According to Donald Norman, there is a significant correlation between the functionality and emotional design of the packaging. Therefore, how to integrate intelligent packaging with design technology cleverly and optimize design efficiency, quality, and consumer experience is the goal pursued by intelligent packaging design. Intelligent packaging design technology can improve design efficiency, quality, and interactivity, significantly enhancing product-added value, brand influence, and market competitiveness.

## **2.2 Development trend of intelligent packaging design.**

Intelligent packaging design is a field that applies artificial intelligence technology to packaging design. It combines new technologies, such as the Internet of Things, artificial intelligence, and machine learning, with intuitive perception, intelligent decision-making, and autonomous interaction capabilities. The integration of these technologies enables smart packaging to achieve a higher level of interaction with consumers, providing personalized services tailored to individual consumers and increasing the degree of product personalization and attractiveness. Intelligent packaging design focuses on enhancing the user experience, convenience, and operability, ultimately improving the quality and market competitiveness of packaging design. At the same time, intelligent packaging design will focus on recyclability and degradability, reducing environmental pollution and resource waste by improving the degradability and recyclability of packaging materials[3]. Future intelligent packaging design will focus on enhancing the user experience, sustainability, intelligence, and safety, which will significantly impact the development of the packaging industry and product sales. Integrating AI, AR, VR, cloud computing, and big data technologies will allow intelligent packaging to achieve a higher level of interaction with consumers, personalized design, and tailored services, thereby increasing the product's personalization and attractiveness and enhancing consumer desire to purchase and loyalty. Intelligent packaging design will also focus on enhancing the quality and market competitiveness of packaging design by improving the user experience, convenience, and operability. Additionally, intelligent packaging design can improve safety, reliability, anti-counterfeiting, and protection properties through intelligent sensing and automation control technology, achieving real-time monitoring. Components of intelligent packaging design

## **3 Components of intelligent packaging design**

The constituent elements of intelligent packaging design include materials, data, socio-cultural context, and user experience. Intelligent packaging technology can provide clear product traceability information and improve food safety and drug quality through IoT technology, a major application area of intelligent packaging technology. At the same time, intelligent packaging technology can also improve the convenience of products through reusable sealing technology and intelligent delivery services and realize customized product appearance, function, or services. Strengthening the safety of packaging can prevent the circulation of counterfeit and substandard products, ensuring the safety of product use for consumers. In addition, the connection between intelligent packaging technology and smart devices can enable interactive experiences with the packaging, allowing users to understand product knowledge and information better. The experiential functions of intelligent packaging are comprehensive and need further expansion. The development of intelligent packaging technology will provide users with better product and service experiences and extend to more application areas and commercial opportunities.

### 3.1 Material technology of intelligent packaging

With the development of nanotechnology, intelligent materials, and other technologies, research on intelligent packaging materials has become increasingly mature. For example, Youssef et al. studied the function and performance of nanomaterials in intelligent packaging, tested the biodegradability, thermal stability, and antibacterial activity of the packaging, and found that nanomaterials can increase the shelf life, quality, and marketability of different packaging materials [4]. Intelligent packaging materials prepared using nanotechnology can achieve micro-control and intelligent response to the packaged goods, achieving intelligent protection and control. With the successful development of manufacturing and logistics industries, intelligent packaging has become a highly anticipated emerging technology. It needs to actively intervene and guarantee product quality and circulation safety and achieve real-time monitoring and data collection of goods. Therefore, material science and technology must provide high-performance materials and technologies to support the practical needs of intelligent packaging. In recent years, the emergence of new materials and the progress of material science and technology have greatly expanded the types of intelligent packaging materials [5]. Common intelligent packaging materials include paperboard, wood board, foam, plastic, metal, etc. The material selection for intelligent packaging needs to consider not only the cost of materials but also factors such as the application scenario, natural environment, and transportation mode of the goods.

Functional material-based and structural-based packaging are the two main categories of intelligent packaging [6]. Functional material-based packaging is used for product function indication and long-distance transportation, and its material can trigger or respond to relevant information under specific conditions, achieving intelligent functions. Sensors in functional material-based packaging can transmit data to the cloud for real-time monitoring and remote control. Actuators are materials that can perform specific actions, such as controlling the packaging's opening, deformation, and color changes. Optical materials can indicate the status or changes inside the packaging, such as displaying the internal air pressure and humidity. Chemical reaction materials can undergo chemical reactions under specific conditions and can be used to detect gas concentration, PH value, and other indicators inside the packaging. [7] Functional material-based packaging has a broad application prospect and can be used in food packaging, drug packaging, electronic product packaging, etc [8]; the Nespresso smart coffee capsule packaging is an excellent example of personalized packaging that can recognize the flavor and type of the capsule, and automatically adjust the water quantity and temperature of the coffee machine to ensure the quality and taste of the coffee (Fig. 1). It can provide more information and convenience for consumers and help production enterprises achieve intelligent production and logistics management.

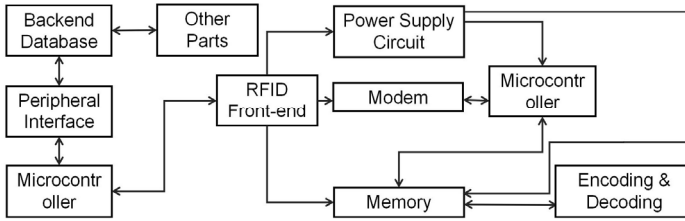


Fig. 1. Nespresso Intelligent Coffee Capsule Packaging.

### 3.2 Data technology for intelligent packaging

Intelligent packaging design combines user thinking and technological capabilities to innovate design. The application and integration of IoT data technology connect packaging with the internet, enabling precise and efficient packaging. Intelligent packaging design can customize packaging according to consumer needs by analyzing their behavior, interests, and preferences. Technological advancements such as sensors make data monitoring in packaging more intelligent, collecting environmental data from inside and outside the package, including temperature, humidity, air pressure, product location, and transportation status. This collected data can help production companies better control and manage their supply chain, reducing damage rates and providing efficient, high-quality, and environmentally friendly services.,thereby improving the market competitiveness of manufacturing companies or groups [9].

Intelligent packaging can provide better product protection and reduce waste and complaints, benefiting brand differentiation design. RFID tag technology is a promising packaging technology that uses wireless radio frequency for contactless bidirectional communication (its operation mode is shown in Fig. 2). RFID packaging can track and monitor packaging through an embedded RFID chip, which enables full traceability and real-time management throughout the entire chain, thereby enhancing product safety and inventory management efficiency, while reducing loss and damage rates. Avery Dennison's RFID tag (Fig. 3) represents this product type. In this way, production companies can better understand the condition of their products, effectively control and manage their supply chain, improve production efficiency, and reduce costs. Developing better integration of intelligent systems in packaging materials is crucial for cost reduction [10].



**Fig. 2.** RFID System Operation Mode.

Intelligent packaging is enhanced by IoT technology and cloud computing platforms, enabling end-to-end traceability and monitoring. However, data security and privacy protection must be considered. Production enterprises should implement security measures to safeguard against data attacks and theft. Personal information and privacy in intelligent packaging must be protected to prevent leakage and abuse. Integrating data technology in intelligent packaging can help production enterprises better understand the market and customer demands, improve efficiency, and provide consumers with safer, more convenient, and more efficient products and services.



**Fig. 3.** Avery Dennison's RFID tags.

## 4 The application value of intelligent packaging design

Intelligent packaging provides new digital-based business opportunities more suitable for the wider industrial field of Industry 4.0 [11]. Designers must constantly innovate to meet the demands of sustainable development and industrial transformation. They can use novel structures, materials, and printing technologies to optimize packaging design and improve its usability and sustainability to meet the needs of different industries and consumers [12]. However, it is more important for designers to think holistically about the fundamental attributes of design and the development trend of artificial intelligence. They should use rational thinking and a long-term vision to achieve true "upgrading" in the era of artificial intelligence.

### 4.1 Value map of intelligent packaging

Intelligent packaging is a growing field with diverse applications in various industries, such as food, medical, home, and electronics. As product safety and differentiation become more critical in manufacturing, intelligent packaging has experienced explosive growth. It is crucial to establish intelligent packaging design's value system and application methods by clarifying its development elements and design misconceptions. (Fig. 4). Intelligent packaging solves business problems in production and sales while improving brand image. It requires a closed-loop one-stop service to satisfy design needs from demand to logistics. For example, digital printing technology makes the production of intelligent packaging more flexible and efficient.



Fig. 4. The development factors of intelligent packaging.

Integrating intelligent packaging with technologies such as artificial intelligence and the Internet of Things forms a hierarchical linkage of "online-logistics-users," which runs through the entire life cycle of product packaging. Specifically, this involves the joint participation of consumption, production, and transportation in optimizing and reconstructing the links in the consumption experience, online services, and logistics transportation, and constructing the intelligent packaging system map (Fig. 5) from three aspects of the demand layer, management layer, and resource layer of the intelligent packaging design value system. Integrating new technologies and materials in packaging can optimize the consumption scenario. Data-driven management and visualization monitoring allows for intelligent sensing, control, and interconnection capabilities, meeting the needs of enterprises for packaging product information collection, management, and after-sales functions. This achieves the mutual connection of technology and packaging and people and packaging.

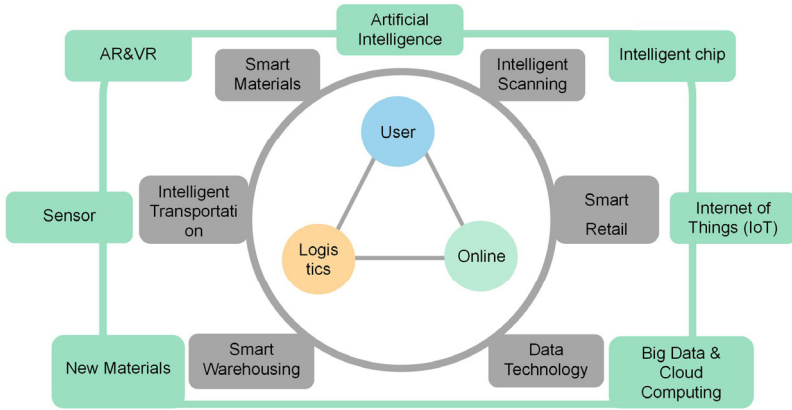


Fig. 5. Intelligent packaging system mapping.

### 4.2 The marginal value of intelligent packaging

Intelligent packaging design involves multiple fields [13], such as art design, service design, science and technology, operational management, and data calculation. (Fig. 6). Intelligent packaging design involves primary and marginal values, which interact to create a complete framework. The primary value refers to direct functions provided by intelligent packaging, while marginal value refers to additional benefits. Intelligent packaging combines various technological elements, such as sensors and software, to optimize production costs, transportation safety, supply chain efficiency, consumer experience, and environmental protection. For instance, sensors can sense packaging vibration and humidity, providing timely warnings to prevent product damage or contamination during transportation. For instance, Cheng et al. expanded the marginal value of cosmetics through intelligent technology, solving conflicts in the production process through cosmetics product decomposition, expandable modeling, extensible analysis, and extensible transformation [14]. Therefore, only by fully understanding the value objectives of intelligent packaging design can its value system be planned to create richer and fuller marginal value for businesses.

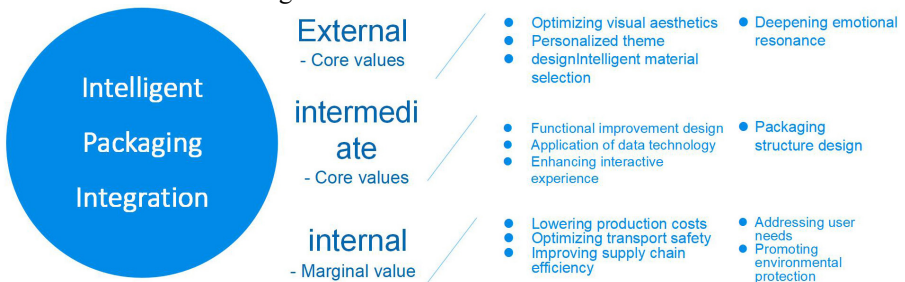


Fig. 6. The development factors of intelligent packaging.



The realization of marginal packaging value depends on the protective function of goods and the design thinking of the product's entire life cycle [15]. This paragraph discusses the importance of exploring potential user needs and consumer psychology in intelligent packaging design. By incorporating consumer psychology, designers can create product functions and visual elements that align with consumers' purchasing intentions and needs. For example, children's product packaging should balance safety and environmental protection with fun and interactive features to increase consumer interest. Increasing additional functions in packaging can also extend a product's life cycle and enhance mainstream consumers' purchasing desires. Designers should aim to transform the production process into more environmentally friendly methods to promote the continuous improvement of intelligent packaging design value.

## **5 Summary & Conclusion**

Artificial intelligence technology can improve packaging design by providing more accurate and attractive solutions for businesses, improving brand value and competitiveness. However, the development of intelligent packaging is still in its early stages and faces challenges such as poor user experience, high manufacturing costs, and technical thresholds. Designers should prioritize safety, sustainability, and cost issues, adopt environmentally-friendly materials and technologies, and focus on practicality and human-centered design. They should also focus on technological innovation and improving production efficiency to reduce costs. Governments and industry associations should enact policies and standards to regulate production and sales behavior to improve the development and quality of the industry. To summarize, intelligent packaging design needs to integrate technology, environmental protection, and aesthetics to improve the added value and market competitiveness of packaging. As artificial intelligence technology continues to develop and be applied, businesses will increasingly value and utilize intelligent packaging design, providing them with more business opportunities and competitive advantages.

## **AUTHORS CONTRIBUTIONS**

Lanyu Liu, Zheng Wang performed the data analysis and performed the Software; Chaowei Wang performed the validation and wrote the Original Draft, manuscript.

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