ISSN:2790-1661 Volume-13-(2025)

Virtual fitting technology for smart e-commerce: a review and outlook of deep learning approaches

Zhenyu Peng*, Yangyi Zhang, Jianan Wang, Junzhe Liu, Xiangrui Zhang, Yilin Li

School of Economics and Management, Tiangong University, Tianjin,China

1679289199@qq.com

Zhenyu Peng*, Yangyi Zhang, Jianan Wang, Junzhe Liu, Xiangrui Zhang are co-first author

Abstract. The rise of virtual fitting technology is redefining consumers' online shopping experience, especially in the field of smart e-commerce. The rapid development of deep learning technology provides strong technical support for virtual fitting system, which not only improves the accuracy of 3D human body modeling, but also greatly enriches the clothing simulation and interaction. This paper reviews the development of virtual fitting technology, analyzes the key applications of deep learning in 3D modeling, dress image generation, and user experience optimization, discusses the commercial potential and practical scenarios of virtual fitting, and at the same time, makes an in-depth analysis of its technical and commercial challenges, and proposes the direction of future development, with a view to providing theoretical support and innovative ideas for the field of smart e-commerce.

Keywords: virtual fitting; deep learning; 3D modeling; generative adversarial networks; smart e-commerce.

1. Introduction

The rapid development of e-commerce has revolutionized the way people shop, but it has also brought new challenges. Online shopping lacks an actual try-on experience, which not only leads to uncertainty in consumers' decision-making, but also directly contributes to a high percentage of return problems[2]. Virtual fitting technology has emerged, and its core goal is to reproduce the real fitting experience in a virtual environment, provide consumers with a more intuitive product display, and effectively solve the size and style selection problem in online shopping[4]. With the rapid iteration of deep learning technology, virtual fitting systems have made breakthroughs in 3D modeling, clothing dynamic simulation and interaction experience optimization[6]. This paper aims to comprehensively discuss the development of virtual fitting technology and the application of deep learning, and sort out its potential value and future development direction in the field of smart e-commerce.

2. The development and current situation of virtual fitting technology

2.1 The origin and development of virtual fitting

Virtual fitting technology was initially realized through the simple superimposition of flat images, which can show the appearance of clothing, but lacks a sense of reality and user participation[1]. With the maturity of 3D modeling technology, three-dimensional fitting based on user body data has become possible. Three-dimensional virtual fitting breaks through the limitations of traditional technology and can not only accurately present the appearance and shape of the garment, but also simulate its dynamic characteristics, such as the suppleness of the fabric and the change of the garment under different movements.

In recent years, the rise of Virtual Reality (VR) and Augmented Reality (AR) technologies has further boosted the development of virtual fitting. Through immersive environments, consumers can experience the fit of garments in multiple dimensions, and this combination of high interactivity and realism is becoming the core competency of virtual fitting.

2.2 Introduction of deep learning techniques

The introduction of deep learning has injected new vitality into virtual fitting. Its powerful feature extraction and data processing capabilities enable the virtual fitting system to more accurately construct human body models, generate clothing effects, and optimize the user interaction experience. The application of deep learning is no longer limited to static display, but is expanding to dynamic simulation and personalized recommendation, which opens up new possibilities for intelligent e-commerce.

3. Applications of Deep Learning in Virtual Fitting

The application of deep learning technology is the core driving force behind the rapid development of virtual fitting. By leveraging deep learning models, virtual fitting systems can achieve precise human body modeling and simulate complex clothing dynamics, further enhancing the intelligence and personalization of the user experience.

3.1 3D Human Body Modeling and Dynamic Optimization

Three-dimensional human body modeling is a core technology in virtual fitting, directly determining the realism and fit of the virtual try-on experience[8]. Traditional methods for body modeling rely on laser scanning or structured light scanning devices, which, despite their high precision, are costly and complicated to operate[5]. In contrast, deep learning technology employs data-driven methods to enable cost-effective and efficient body modeling.

Convolutional Neural Networks (CNNs), a representative technology in deep learning, can extract key human body feature points (e.g., shoulder width, waist circumference, hip circumference) from front and side 2D images to generate high-precision 3D human body models. This image-based modeling approach eliminates the need for expensive hardware, requiring only a standard smartphone for basic data collection, significantly lowering the threshold for modeling.

Furthermore, to meet the demands of dynamic fitting, deep learning models integrate parametric modeling methods, establishing a mapping relationship between body dimensions and the shape space. This process allows for the rapid generation of 3D human body models in different postures and movements, enabling users to experience virtual fitting in various scenarios. The introduction of dynamic optimization models ensures that every movement of the user is captured and rendered in real-time, injecting greater flexibility and realism into the virtual fitting process.

Notably, the integration of multi-modal data further enhances modeling accuracy. By combining RGB images, depth images, and point cloud data, deep learning models effectively filter noise and restore intricate details. This technological breakthrough is particularly suited to the modeling needs of diverse body types, postures, and complex scenes, laying a solid foundation for the broader adoption of virtual fitting across a wider user base.

3.2 Garment Effect Generation and Simulation

Having a 3D human body model alone is insufficient to provide a complete fitting experience; the representation of clothing on the body is equally critical. The introduction of Generative Adversarial Networks (GANs) enables virtual fitting systems to generate high-quality simulations of clothing dynamics. GANs, through adversarial learning between generators and discriminators, can realistically simulate how clothing conforms to the body, including wrinkles and lighting effects[7].

In terms of dynamic garment simulation, GANs' deformation modules play a crucial role. They can adjust the clothing's form in real-time according to changes in the user's body shape and posture. For instance, loose clothing can be simulated to sway during movement, while the fit of tailored clothing on different body shapes can be realistically portrayed. This high level of dynamic simulation allows consumers to perceive the softness, elasticity, and comfort of garments through virtual fitting, providing more intuitive support for purchase decisions.

Additionally, GANs support diverse scene simulation functionalities. For example, under varying lighting conditions (such as indoor lighting or outdoor sunlight), GANs can adjust clothing colors, textures, and reflective effects, enabling consumers to comprehensively experience how the garments appear in real-world scenarios. This diversity in the virtual fitting experience not only boosts consumer trust in the system but also adds an element of enjoyment to shopping.

GANs excel in detailed rendering as well. By accurately generating fabric textures, stitching details, and reflective effects, GANs provide consumers with an experience that closely approximates reality. This meticulous representation significantly enhances consumer confidence in purchasing decisions and helps brands stand out in a highly competitive market.

3.3 Intelligent Optimization of User Experience

The ultimate goal of virtual fitting is not merely technical achievement but also improving the consumer shopping experience through technological advancements. Deep learning algorithms offer numerous possibilities for enhancing user experience.

First, personalized recommendation systems are a critical application of deep learning in virtual fitting. By analyzing users' historical data, shopping preferences, and fitting behaviors, the system can accurately recommend clothing that suits their body type and style. Combined with current fashion trends, the recommendation system can also provide styling suggestions, helping users quickly find the most suitable products. This personalized service greatly improves customer satisfaction and adds an element of fun to the shopping process.

Second, deep learning has driven the development of multi-modal interaction methods. Traditional virtual fitting systems rely on mouse or touchscreen operations, whereas the introduction of voice recognition and gesture recognition technologies allows users to interact with the system more naturally. For example, consumers can use voice commands to switch clothing colors or gestures to adjust fitting angles. This touchless operation not only enhances user convenience but also presents potential applications for offline retail scenarios.

Finally, the real-time inference capabilities of deep learning ensure faster fitting feedback. Consumers can obtain high-quality virtual fitting results without lengthy waits during the try-on process. This real-time feedback significantly enhances the smoothness of the user experience and provides robust support for dynamic fitting functionalities.

4. Business value and application of virtual fitting

4.1 Reduce the return rate and cost

Return rate is one of the core pain points in the e-commerce industry. In the traditional shopping mode, consumers are usually unable to accurately determine whether the clothing is suitable for them, resulting in a large number of returns due to size, color or style discrepancies. Through high-precision 3D modeling and clothing simulation technology, virtual fitting allows consumers to experience the effect of clothing intuitively before purchase, thus significantly reducing the return rate. In addition, virtual fitting technology also reduces the waste caused by wrong production and improves the operational efficiency of the supply chain.

4.2 Enhance User Satisfaction and Loyalty

The immersive experience and highly personalized features of virtual fitting make it novel and enjoyable for consumers. For example, consumers can match multiple garments in the virtual environment and compare the fit of different styles. This interaction not only improves users' shopping satisfaction, but also enhances brand loyalty.

4.3 Promoting the formation of new business models

The introduction of virtual fitting has opened up new business models for smart e-commerce. For example, based on the data analysis of virtual fitting, brands can optimize product design and launch clothing that better meets consumer needs. Meanwhile, virtual fitting also supports the development of "virtual showroom" and "digital fashion", further expanding the market boundary of e-commerce.

5. Challenges and Future Prospects

5.1 Current Technical and Commercialization Challenges

Although virtual fitting technology has made significant progress in recent years, it still faces a number of technical and commercialization barriers in practical application.

First, virtual fitting technology is highly dependent on high-quality data support. Deep learning models require a large amount of accurately labeled 3D human body and clothing data for training, which are very costly to acquire and process. The limited size and diversity of current publicly available datasets can hardly cover a wide range of body shapes, postures, and clothing types, resulting in insufficient generalization ability of the models in complex scenarios. In addition, the physical accuracy of dynamic clothing simulation still needs to be improved. Although the existing technology can generate realistic static effects, it is still insufficient in simulating physical properties such as fluidity and softness of fabrics, which affects the realism of the fitting effect.

Second, the balance between real-time and computational complexity is another key challenge. The virtual fitting system needs to generate the fitting effect quickly after the user's operation, but the complexity of the deep learning model may lead to delays, especially when high-precision rendering and dynamic simulation are involved. This not only puts higher demands on hardware performance, but also challenges the algorithm optimization capability.

The privacy protection issue cannot be ignored in the commercialization process. Virtual fitting involves users' sensitive information, such as body size and personal image data. With increasingly stringent privacy regulations, how to ensure the security of data during storage, processing and transmission has become an important factor limiting the promotion of virtual fitting. In addition, the high cost required for developing and deploying a high-quality virtual fitting system is unaffordable to many small and medium-sized enterprises (SMEs), thus limiting the widespread adoption of the technology in the industry.

5.2 Way Forward

To address the above challenges and unleash the potential of virtual fitting technology, future research and applications should focus on the following directions:

First, technology integration and optimization. By combining cutting-edge technologies such as 5G communication, blockchain and artificial intelligence, virtual fitting systems can realize more efficient and safer services. For example, blockchain technology can provide encryption guarantee for the storage and sharing of user data, while the low-latency feature of 5G helps to improve the real-time feedback capability of dynamic fitting. In addition, the optimization direction of deep learning models should focus on reducing the consumption of computing resources while maintaining high accuracy to achieve lightweight and efficient deployment of models.

Second, the synergistic application of cloud computing and edge computing. Cloud computing can provide powerful computing power support, while edge computing can share part of the real-time processing tasks, reduce latency and improve user interaction experience. For example, during the try-on process, the user's basic operation data can be initially processed in the edge device, and then the complex rendering task can be handed over to the cloud for high-precision computation. This collaborative approach not only improves system efficiency, but also reduces the performance requirements for user terminal equipment.

Third, it promotes large-scale commercialization and multi-scene expansion. By reducing technical costs and improving the universality of the model, virtual fitting is expected to be applied in a wider range of scenarios. For example, combining AR devices in retail stores to provide immersive fitting services, or integrating virtual fitting functions on social media platforms to enhance consumers' social experience. In addition, the further improvement of personalized recommendation systems and dynamic interaction functions will drive virtual fitting to become an important part of smart e-commerce, bringing greater commercial value to the industry.

6. Conclusion

Virtual try-on technology has evolved from the initial 2D image overlay technology to today's multidimensional interactive systems, which are built on 3D modeling and deep learning. These advances not only satisfy consumer demand for realism and personalization, but also drive changes in e-commerce service models. The integration of deep learning greatly improves the efficiency of 3D human reconstruction, enhances the fidelity of clothing simulations, and facilitates a smarter, more personalized user experience.

However, despite its promising application prospects, virtual try-on technology still faces challenges in areas such as data acquisition, computational complexity, and privacy protection. The difficulty in obtaining high-quality data, combined with the substantial costs of hardware and development, limits the technology’s widespread adoption. Moreover, issues surrounding user privacy and data security remain critical barriers to achieving large-scale commercialization. Future research should therefore prioritize the development of more efficient deep learning models, reduction of data and technological costs, and the establishment of secure, transparent user data management systems.

The rise of metaverse technologies offers new opportunities for virtual try-on. By leveraging the immersive environments and multimodal interaction capabilities provided by the metaverse, virtual try-on could evolve into an integrated service platform encompassing social networking, entertainment, and shopping. Furthermore, as enabling technologies such as 5G and blockchain continue to mature, virtual try-on is poised to further enhance user experiences, support large-scale commercial applications, and emerge as a key driver of intelligent e-commerce innovation.

In summary, virtual try-on technology represents not only a critical tool for advancing intelligent e-commerce but also a pivotal component of the future digital consumption ecosystem. Through continuous technological innovation and the refinement of business models, this field holds the potential to transform shopping practices and propel the apparel industry toward greater personalization, efficiency, and sustainability.

References

[1] Zhang, H., Wang, Y., & Zhao, C. (2024). Design of virtual fitting rooms under service design thinking. Industrial Design, 10, 147–151.

[2] Xie, X., & Qu, H. (2024). The impact of virtual fitting experiences on consumers’ purchase intentions. Journal of Xi’an Polytechnic University, 38(4), 33–41. https://doi.org/10.13338/j.issn.1674-649x.2024.04.005

[3] Cui, X., & Zhu, L. (2024). Analysis of the application value and prospects of metaverse virtual try-on. China Apparel, 9, 56–58.

[4] Mai, Y., & Hu, C. (2024). The development and integration of virtual fitting rooms in the digital-intelligent world of the metaverse. Computer Knowledge and Technology, 20(13), 113–115. https://doi.org/10.14004/j.cnki.ckt.2024.0680

[5] Li, J. (2020). 3D human perception and clothing image generation based on deep learning (Master’s thesis, Zhejiang University). https://doi.org/10.27461/d.cnki.gzjdx.2020.003858

[6] Xia, H. (2020). Research on virtual fitting methods based on machine learning (Master’s thesis, Zhejiang Sci-Tech University). https://doi.org/10.27786/d.cnki.gzjlg.2020.000643

[7] Zhang, Y., & Liu, C. (2021). Research progress on the application of generative adversarial networks in virtual try-on. Silk, 58(12), 63–72.

[8] Tong, H. (2024). Digital clothing applications based on 3D human body modeling. Shanghai Garment, 1, 29–31.