Real-Time Artificial Intelligence (AI) and Augmented Reality (AR)-Driven Virtual Saree Dressing: Mirroring Reality in Fashion Technology

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Abstract—**In India, traditional saree stores frequently encounter challenges in providing fitting rooms, which impedes customers from confidently exploring saree options. This limitation stems from various factors, including space constraints within the stores and the intricate process of draping a saree, which can be time-consuming and challenging in a fitting room setting. Additionally, expanding the stores to accommodate fitting rooms may not always be feasible due to limitations in space or resources. As a result, customers often face difficulties assessing the fit and a high rate of returning the saree. Virtual dressing and leveraging immersive technologies revolutionize traditional shopping by integrating Augmented Reality (AR) and real-time Artificial Intelligence (AI). This paper addresses this challenge with an innovative method that combines AR and AI algorithms to integrate virtual sarees and simulate fabrics in real-time seamlessly. A smart mirror application has been developed in this research, functioning as a virtual dressing room. Positioned strategically, the mirror allows customers to effortlessly scan their measurements and use AR to virtually drape various saree styles, empowering them to make informed selections. The implementation results show that the proposed approach can enhance the in-store shopping experience and mitigate uncertainty associated with saree draping, providing a real-time, interactive reflection to boost confidence in offline saree selections. This innovative blend of technology and tradition transforms the saree shopping journey, bridging the virtual and physical realms for an enriched customer experience.**

Keywords—**augmented reality, artificial intelligence, virtual fitting room, smart mirror, virtual try-on, traditional shopping, saree draping**

I. Introduction

The integration of conventional garments with modern gadgetry has created new opportunities for improving the customer experience in the fashion trade. Unquestionably, the saree is one of the most important cultural symbols within South Asia and is widely used in India, Sri Lanka, Bangladesh, and Nepal, where this piece of cloth has evolved traditionally, artistically, and as craftsmanship over the years. Sarees are particularly worn at functions such as festivals and wedding occasions. With the global estimates of the saree market standing at 6.5 billion USD, India alone is meeting 90% of the market. Indeed, sarees account for around one-third of the total Indian women's apparel market, and the Indian saree market is expected to reach 8 billion USD by the financial year 2025. However, saree shopping becomes a relatively daunting task, especially since one cannot try sarees from fitting rooms. Wearing a saree is elaborate, and because this kind of attire covers the entire body, most ladies find it uncomfortable to undress to their underwear while doing trials in fitting rooms. Also, trial sarees, used by several models and changed in succession, create hygiene problems, as sweat and contact are sure passages for germs. In addition, since everyone wears a saree in varying styles and the fabric's length is standardized, the design may appear different for taller or shorter-built women. Just fitting a saree on a model or draping it might also give wrong impressions, leading to buyer's disappointment.

This paper explores the dynamic fusion of augmented reality and real-time artificial intelligence technologies to address these challenges, presenting a bespoke virtual dressing system tailored specifically for the traditional Indian saree. This paper first introduces a modular framework for achieving an interactive magic mirror using identified technologies and tools. Based on this framework, a smart mirror application has been developed and tested to empower customers to effortlessly scan their measurements and leverage Augmented Reality (AR) to drape a myriad of saree styles virtually in real time. It provides an authentic and captivating AR try-on

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experience, enabling customers to visualize sarees' fit, design, and color before making a purchase decision. This research not only addresses the practical challenges associated with saree shopping but also marks a convergence of tradition and innovation, marrying the timeless allure of the saree with the transformative potential of immersive technologies.

II. Literature Review

In recent decades, technological advancements have spurred researchers and developers to explore innovative solutions for enhancing human-machine interaction, particularly in virtual dressing. Initially, researchers like Peng [1] faced challenges in developing mobile applications for virtual dressing due to limitations in screen size, image quality, and processing power. However, as mobile terminal technology evolves, these drawbacks are expected to diminish, paving the way for new research directions in virtual dressing technology.

In 2013, inspired by the need to improve online shopping experiences, Zeekit, a fashion IT startup founded by Vizel [2], introduced a virtual fitting room software to reduce online clothing returns. This innovation provided a personalized shopping experience by allowing users to virtually try on clothes using their photos and body measurements. Despite its advantages, the static representation of virtual clothes limited users' ability to fully evaluate realism and make informed purchase decisions. This limitation highlighted the need for more dynamic and interactive solutions. Based on this foundation, Raturi [3] developed the "Virtual Mirror" system in 2018, significantly enhancing the user experience by enabling users to try on clothing through realistic simulated motions virtually. This system utilized scanned garments and a virtual mirror to create a more immersive experience. However, its high development cost restricted its use to in-store settings, excluding online shoppers and pointing to the need for more accessible solutions.

Recognizing these limitations, Moroz [4] explored the potential of Virtual Fitting Rooms (VFRs) for Generation Y consumers, focusing on using 2D VFRs based on augmented reality. They found that VFRs, acting as "virtual mirrors," helped consumers make more informed purchasing decisions and reduced the number of client refunds. However, their study also noted the challenges in accurately mapping clothing onto the user's form, particularly with 3D overlays, suggesting that further refinement was needed.

In 2020, addressing the call for more accurate and user-friendly virtual fitting solutions, Kore *et al*. [5] proposed a marker-based AR solution for online retailers. Their approach leveraged technologies like Vuforia and AR Core to create a virtual clothes-fitting application that allowed users to see 3D models of garments superimposed on their bodies. While this method offered greater convenience and accuracy, it was highly dependent on the quality of the garment images provided by users.

Expanding on these advancements, Wang *et al*. [6] in 2021 introduced Smart Mirror Fashion Technology (SMFT), which revolutionized the retail experience by eliminating the need for physical clothing changes. By integrating electronic displays with mirrors, SMFT provided a seamless browsing experience for customers. Despite its innovative approach, challenges in implementing SMFT in physical stores and understanding patron interactions remained.

Lee and Xu [7] in 2021 delved into the promise of Virtual Fitting Rooms (VFRs) in addressing fit-related challenges for retailers. They classified VFR technologies based on their impact on cognitive and affective dimensions, highlighting the importance of affective experiences in consumer perception. Their research addressed concerns about simulation accuracy, which hindered widespread adoption, underscoring the need for improvements in this area. In the same year, Dini *et al.* [8] further investigated the impact of VFRs on consumer behavior and perception in retail settings. Their study provided insights into how VFR technologies influence cognitive and affective dimensions, shedding light on these technologies' potential benefits and limitations. This research highlighted the importance of cognitive and emotional factors in adopting virtual fitting technologies.

Beyond the specific context of virtual dressing, Rovai *et al.* [9] explored the impact of Artificial Intelligence (AI) on luxury retailing, particularly its contribution to the hedonic dimension of the shopping experience. This study focused on how AI could enhance curiosity, enjoyment, and entertainment within the store environment, suggesting that similar advancements could be applied to virtual dressing technologies to improve user engagement. Continuing this exploration, Hollebeek *et al.* [10] addressed the increasing importance of understanding how consumers interact with brands, particularly in social media. They developed a reliable scale to measure Consumer Brand Engagement (CBE) in the digital age, providing insights that could inform the development of more engaging virtual dressing technologies. Similarly, Cattapan *et al*. [11] investigated the role of omnichannel integration in reducing perceived risk and increasing customer satisfaction, which in turn boosts purchase intentions for luxury fashion products among Thai Millennials. The authors highlighted the significance of integrated product, price, promotion, and information access in shaping consumer behavior in the context of omnichannel retailing.

Another significant contribution came from Pambudi *et al.* [12] in 2022, who examined the transformation caused by omni-channel retailing, highlighting its impact on customer satisfaction and loyalty. They emphasized the role of perceived customer empowerment in enhancing patronage intentions and underscored the importance of consistent service levels across all channels. This research indicated that integrating virtual dressing technologies within an omni-channel retail strategy could provide consumers with a seamless and satisfying shopping experience.

Singh *et al*. [13] investigated the role of omnichannel integration in reducing perceived risk and increasing customer satisfaction, which in turn boosts purchase intentions for luxury fashion products among Thai Millennials. The authors highlighted the significance of integrated product, price, promotion, and information access in shaping consumer behavior in the context of omnichannel retailing. Following this, Holte [14] concluded that virtual dressing rooms show promise in reducing return rates in online clothing shopping by improving size and fit assessments. Although they didn't surpass traditional fitting rooms or web shops in all areas, their ability to provide accurate fit information can help tackle the main reasons for returns.

In a related study, Silva *et al*. [15] investigated the use of Virtual Reality (VR) for virtual dressing. They found that VR provided an even more immersive experience than AR, allowing users to interact with virtual garments in a fully 3D environment. This research suggested that future virtual dressing technologies could benefit from incorporating VR elements to enhance user engagement. Moreover, Wu [16] examines how VR and AR technologies impact consumer purchase intentions for fashion brands. Using Self-Determination Theory (SDT), the research identifies key drivers, such as perceived value, enjoyment, informativeness, presence, and consumer experience, which positively influence purchase intentions in the context of AR/VR marketing in the fashion industry.

Patel *et al.* [17] examined the use of holographic displays for virtual dressing applications. Their research demonstrated that holographic displays could provide a highly realistic and interactive virtual try-on experience. However, the technology is still in its early stages and requires further development to be commercially viable. Continuing this trend, Nahavandi *et al*. [18] explored the use of wearable technology to enhance virtual dressing applications. By integrating sensors into clothing, they could provide real-time feedback on fit and comfort, offering a more comprehensive virtual try-on experience. This study highlighted the potential for combining wearable technology with virtual fitting solutions to create a more holistic and engaging user experience.

In a similar vein, Huang *et al*. [19] investigated the application of smart mirrors in virtual dressing rooms. Their research showed that smart mirrors could provide a seamless and interactive virtual try-on experience, allowing users to view themselves in different outfits without physically changing clothes. This technology offers a promising solution for both online and offline retail environments. In 2024, Atetedaye [20] explored the potential of blockchain technology to enhance the security and transparency of virtual dressing applications. By using blockchain to verify the authenticity of virtual garments and ensure secure transactions, they addressed some of the key concerns related to the adoption of virtual fitting technologies in the retail sector.

In summary, whilst technological advancements have enabled innovative solutions for enhancing the retail experience, challenges remain regarding accuracy, realism, and widespread adoption. Future research should address these challenges and explore the synergies between different technologies to create seamless and immersive retail experiences for consumers.

III. Proposed Framework

This study aims to create an AR virtual fitting room using a Magic Mirror (smart mirror) that utilizes AR and Motion Tracking technology. In response to the evolving landscape of fashion retail, this study introduces an effective addition to physical saree shops—an interactive magic mirror designed to elevate the traditional saree shopping experience. Positioned as an AR virtual dressing room, this intelligent mirror allows customers to enter a world where their chosen saree comes to life.

The workflow is planned and divided into modules, each serving as a stepping stone to achieve the final output. Each module is designed to be a distinct stage of development in the project, ensuring that the expected outcomes are achieved at every developmental stage. The following flowchart in Fig. 1 illustrates the structured progression through these modules, highlighting the systematic approach taken to develop the AR virtual fitting room.

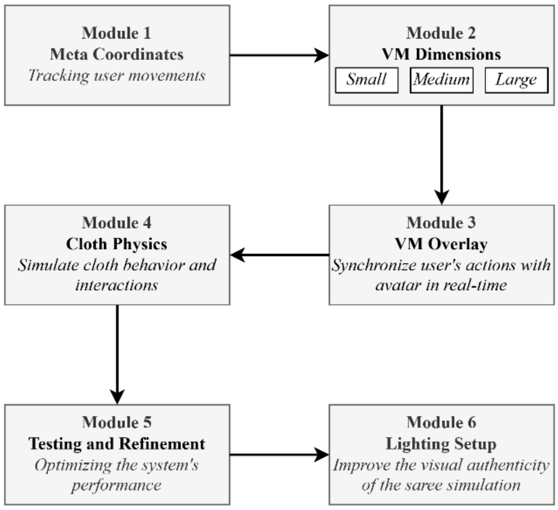

Fig. 1. Workflow of the modules.

A. *Module 1: Meta Coordinates*

The core of the system is "Meta Coordinates," which makes it possible to track coordinates in real-time and makes debugging easier. This module receives real-time video data from cameras as its input. This Module processes the incoming video data by using computer vision libraries like Mediapipe to extract meta-coordinates, as shown in Fig. 2, which are important spatial information inside the AR environment. The system may then precisely follow the location and motion of objects or subjects within the camera's field of view by using these meta-coordinates for live tracking. Coordinate tracking procedures include extensive error detection and diagnostic procedures that enable fast identification and resolution of any discrepancies or problems like Noise filtering, Data Validation, etc. To sum up, Module 1 is essential to the system since it tracks meta-coordinates in real time.

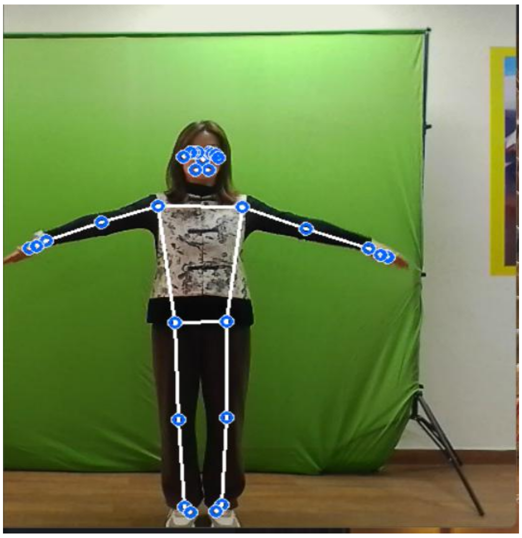

Fig. 2. Meta Coordinate points are identified for a user whose posture is captured in the camera (Module1).

B. Module 2: VM Dimensions

The second module deals with Virtual Modelling (VM) and avatar customization in the context of producing realistic representations of people in a range of sizes. The virtual model avatar and measurements from several fashion brand websites that indicate typical body dimensions like height, waist-to-hip ratio, etc. make up this module's two key inputs. Module 2 uses Clo3D software to process the input data and create three different avatars: one for small, another for medium, and a third for large sizes. The average measurements obtained from the gathered data are used to develop these avatars, ensuring they closely resemble real bodies' proportions.

Additionally, Module 2 incorporates an advanced system that applies mathematics to determine the ideal avatar size for each particular consumer. This method uses the meta-coordinates that users provide during their interactions with the system. The program evaluates if the customer's measurements align with the small, medium, or large avatar size by examining these coordinates and comparing them to predetermined thresholds. This feature makes it possible to choose an avatar that is unique to each customer's body type, improving the entire virtual fitting experience.

C. Module 3: VM Overlay

To integrate virtual avatars into the user experience and enable smooth communication between the user and the selected avatar, Module 3, entitled "VM Overlay," is essential. This module functions by utilizing the inputs produced by the preceding two modules, which are included within an algorithmic structure. The computational outputs from Modules 1 and 2, which together determine the appropriate avatar size based on user measurements and allow the tracking of user motions, are the main input to Module 3. Module 3 takes advantage of this input by providing real-time synchronization between the user's actions and the selected avatar.

The primary purpose of Module 3 is to allow the selected avatar to mirror the user's movements. To translate the user's actions into equivalent movements for the avatar, this method depends on reading the meta-coordinates produced by Module 1. Module 3 ensures the avatar correctly represents the user's gestures and movements by adding these meta-coordinates to the avatar model.

Essentially, Module 3 facilitates dynamic interaction between the user and the virtual avatar, which is a crucial component in improving user engagement and immersion. A seamless and immersive user experience is created by Module 3 by utilizing inputs from earlier modules and performing advanced movement-tracking algorithms into practice. The avatar replicates the user's movements in real-time, as shown in Fig. 3.

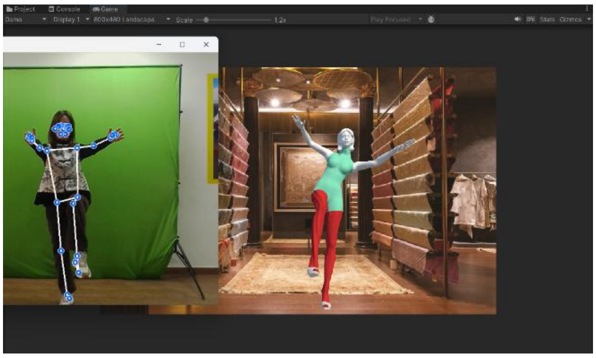

Fig. 3. The avatar follows the user's movements, which is received as input from the previous module.

D. Module 4: Cloth Physics

Module 4 focuses on simulating realistic cloth interactions and behavior. It begins by preparing a virtual cloth model, selecting a simple saree pattern, and determining size and material composition parameters. Texture is added for visual authenticity. Using software such as Maya3D for simulation, Unity3D for avatar integration, and Clo3D for saree design, the module creates a live cloth model integrated with an avatar. This allows for realistic interactions based on user actions, with colliders enabling dynamic cloth behavior in real time. The goal is to enhance the user experience by simulating realistic cloth physics and creating interactive environments where users can engage with virtual cloth models.

E. Module 5: Testing and Refinement

Module 5 focuses on optimizing system performance and fine-tuning the simulated environment. It enhances cloth simulation for avatars of different body sizes, improving the accuracy of virtual components. This involves aligning virtual elements' dimensions with real-world standards to ensure the virtual representation captures the user's physical characteristics and movements, enhancing immersion. The module includes thorough testing of fabric simulation with various body shapes to identify and correct any inconsistencies. The goal is to achieve complete synchronization between the user's actions and the avatar's movements, ensuring the virtual fabric responds realistically. Overall, Module 5 aims to improve the virtual environment and system performance, providing a smooth and immersive user experience through iterative testing and refinement.

F. Module 6: Lighting Setup

Module 6 focuses on enhancing the visual authenticity of the saree simulation by replicating realistic lighting conditions inside the virtual fitting room. This involves adjusting light source direction, color temperature, and intensity to mimic a real fitting room ambiance. Advanced techniques like dynamic shadowing and global illumination are also integrated to improve light interactions with the saree fabric.

The realistic lighting setup enhances the saree's visual appeal and provides a more immersive user experience. By simulating natural lighting conditions, Module 6 ensures the saree looks attractive and lifelike in the virtual mirror, contributing to a high-quality virtual fitting room environment.

IV. Implementation

In order to offer users a dynamic and interactive means of trying on various saree styles, it is critical to integrate AR technologies with real-time AI in the implementation process. In this paper, Unity engine and Python technologies have been selected as enabling tools to create an immersive virtual dressing room using the proposed framework.

A. Body Tracking with Unity and Python

Users initiate the experience by standing in front of a smart mirror equipped with a camera. To enhance the tracking of user movements, the system captures 32 Meta points from the user's body, as shown in Fig. 4. However, this posed significant challenges, as body tracking tools such as OpenPose were usually resource-heavy and only provided 2D coordinates, making it difficult to integrate seamlessly with Unity. To overcome this, the Mediapipe library in Python was adopted that not only lightened the computational load but also improved the connection with Unity. It operates with minimal error in real-time, contributing to smoother data transfer and more accurate 3D tracking of body movements as demonstrated in Fig. 5.

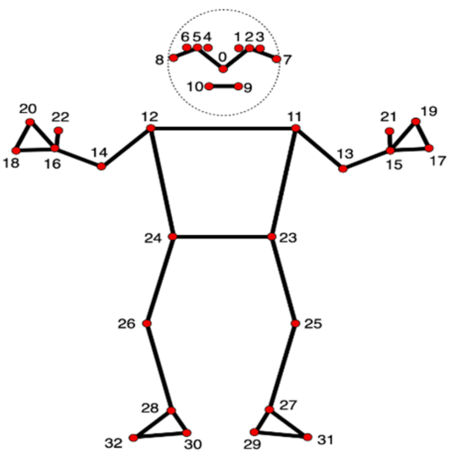

Fig. 4. Meta points taken as input from the avatar.

The Python script handles real-time pose estimations by continuously updating the coordinate data and transmitting it to Unity using a client UDP approach. In Unity (C#), the received data is transformed into a humanoid avatar, reflecting the customer's movements. The humanoid avatar will be dressed in a selected saree, providing a realistic visualization of how the saree would appear on the customer.

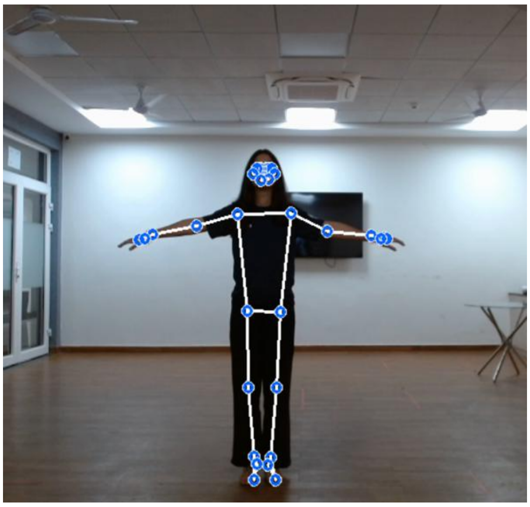

Fig. 5. Capturing meta points in real-time with a person using the Mediapipe library in Python.

B. Smart Mirror Interaction

The smart mirror functions as a virtual fitting room where users can scan their measurements effortlessly. AR technology is employed to drape various saree styles on the user's virtual avatar in real-time. The mirror's AR feature enables customers to visualize different angles, including the front and back, as depicted in Fig. 6, providing a comprehensive view of the saree's fit and appearance. The avatar is now dressed in a specially designed saree. This saree features cloth physics that responds to the movements of the avatar. As a result, the saree will react in real-time to the user's movements.

Fig. 6. Front and back view of the avatar.

C. Customization and User Interface

To enhance realism, the virtual apparel, including the saree, can be seamlessly customized to the user's body. Through the web camera, the virtual garment monitors tracked user body motions, ensuring a perfect fit. The AR experience captures realistic virtual movements, allowing customers to see how the saree adapts to their bodies in real-world scenarios. Unity's Canvas is utilized, as shown in Fig. 7, to craft a user-friendly interface, ensuring intuitive navigation through the virtual saree selection process. This UI design contributes to a seamless and engaging user experience within the physical saree shop. By using Python and Unity, this study offers an innovative solution for offline saree stores, transforming the conventional saree shopping experience into an immersive and technologically advanced journey. The integration of AR and real-time AI brings a new level of interactivity, allowing users to confidently explore and select sarees in a virtual environment.

Fig. 7. UI of the magic mirror.

V. Discussion

As explained in detail in the 'Implementation' section, the proposed system successfully created a virtual saree dressing room application using AR and AI. However, several limitations have been identified during the development and evaluation of this system.

One major issue was the instability of the avatar, particularly when it flexed. This instability affected the synchronization between the avatar and the user's pose and the overall performance. The bending of the avatar may be attributed to errors in pose estimation or the system's inability to capture fast or complex movements.

Another issue has been found during the alignment process between the avatar wearing a saree and the user in real-time, as seen through the smart mirror. The primary challenge lies in the Python script, which collects position data using the Mediapipe library. This library operates in a different coordinate system compared to Unity's Vector3 points. While both systems can estimate rotation and replicate human movement, the discrepancy in coordinate data between Python (data collection) and Unity (data visualization) complicates the precise alignment of the avatar with the person standing in front of the mirror. Currently, the proposed solution involves establishing a designated position for users to stand to experience the saree's feel.

To address these limitations, an enhancement could be made by implementing body tracking and position and rotation directly within Unity, thus eliminating the need for external tools like Python. Other potential approaches include integrating Kinect cameras or utilizing AR Foundation, which allows iOS devices to capture body positions and accurately overlay avatars. However, these methods have drawbacks: Kinect cameras can be expensive, and AR Foundation solutions require iOS devices, which are also costly and only compatible with rear cameras—not front ones. Moreover, these devices often lack the processing power to run the complete model. Alternatively, Unity's OpenCV plugin could be used, but it is a paid asset. In contrast, the current Python approach utilizing Mediapipe is cost-effective, as it tracks body movement with standard cameras, thereby reducing the expenses for specific cameras or devices.

Despite these limitations, the proposed system demonstrates innovation, simplicity, and affordability. In the future, developing APIs to establish seamless communication between Unity and Python could provide a more robust and integrated solution to this mapping issue, further enhancing the overall system.

VI. Conclusion

The Virtual Saree Try-On System revolutionizes traditional saree shopping in India by leveraging augmented reality and real-time artificial intelligence. This modular system effectively addresses challenges such as the absence of fitting rooms and the complexity of draping sarees, providing customers with a seamless and immersive virtual dressing experience. Through real-time coordinate tracking, virtual modeling, cloth physics simulation, and realistic lighting, customers can visualize saree designs and colors on their bodies, increasing confidence and satisfaction in their selections. By combining AR, AI, and fashion retailing, the proposed system has shown the potential for immersive technologies to be integrated into diverse cultural and retail settings and other industries.

Apart from the enhancements to the current in-store shopping experience, limitations of the proposed system were also identified, including Avatar instability, time delays during avatar interaction, and cloth simulation issues. To overcome these, future development work will focus on optimizing pose estimation and real-time alignment processes and refining clothing simulations in virtual environments to ensure a better fit on real bodies.

Moreover, iterations of the proposed system must incorporate emerging technological advancements. The current system can be enhanced with a Smart Recommendation System, which would leverage AI to suggest sarees based on user preferences and body shape. Another promising direction is incorporating gesture-based interactions, enabling a more intuitive try-on experience while reducing reliance on conventional inputs. Additionally, developing a store-specific Virtual Mirror model with Real-Time Social Sharing capabilities would allow users to share their favorite sarees with friends and family in real time. These features would bridge the gap between online and in-store shopping, creating a unified "hybrid shopping" experience that combines both strengths.

APPENDIX: USER FEEDBACK

During the development stage of the Virtual Saree Dressing System (Magic Mirror), feedback was gathered from 33 participants, predominantly women but with a small number of men, to evaluate the system's usability, accuracy, and overall experience. Participants interacted with the prototype version of the Magic Mirror in a controlled environment designed to simulate an in-store shopping experience.

(1) Participants' Overview

- Total Participants: 33,
- Demographics: Primarily women aged 18–45, with a few male participants, all with varying familiarity with Augmented Reality (AR) and virtual dressing technologies,
- Setting: Participants were invited to test the smart mirror during its development stage.

(2) Key Feedback Themes

- Ease of Use: Majority of the participants said that the system was easy to understand and use. It was understood that the ability to try the sarees in the virtual fitting room without having to seek help or complex configurations was easier.
- Accuracy of Visualization: Most of the participants expressed satisfaction with the saree visualization, particularly how it adapted to their body shapes and sizes. Some users mentioned the need for further refinement in how the saree drapes and moves, particularly during body motion, to better simulate real-world experiences.
- Overall Experience: 85% of participants reported an overall positive experience, highlighting that the system reduced the time needed to try on sarees and made the shopping process more interactive and enjoyable. Users appreciated the ability to try on multiple sarees virtually, commenting that the Magic Mirror significantly enhanced their shopping experience by providing a more engaging and personalized approach.

(3) Suggestions for Improvement

While feedback was overwhelmingly positive, participants provided the following suggestions for improvement.

- Enhanced Fabric Simulation: Some participants requested further enhancements in how the fabric flows and responds to movement, particularly to make the saree appear even more realistic.
- AI-Based Recommendation System: Many participants expressed interest in an AI-powered recommendation system that could suggest sarees based on their body type, preferences, or previous selections to further personalize the shopping experience.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Venkatesh C.V.: writing—original draft, methodology, software, analysis, supervision; Keerthivasan R. S.: writing—original draft, software, validation; Guolong Zhong: writing–review and editing, supervision; Prem Kumar: conceptualization, supervision; Man Zhao: conceptualization, supervision; all authors had approved the final version.

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