2023 IEEE 47th Annual Computers, Software, and Applications Conference (COMPSAC) | 979-8-3503-2697-0/23/$31.00 ©2023 IEEE | DOI: 10.1109/COMPSAC57700.2023.00225

Hanfu AR: Digital Twins of Traditional Chinese Costumes for Augmented Reality Try-On Systems

Yukun Fu
School of Advanced Technology
Xi'an Jiaotong-Liverpool University
Suzhou, China
Yukun.Fu16@alumni.xjtlu.edu.cn

Yue Li *
Department of Computing, School of Advanced Technology
Xi'an Jiaotong-Liverpool University
Suzhou, China
Yue.Li@xjtlu.edu.cn

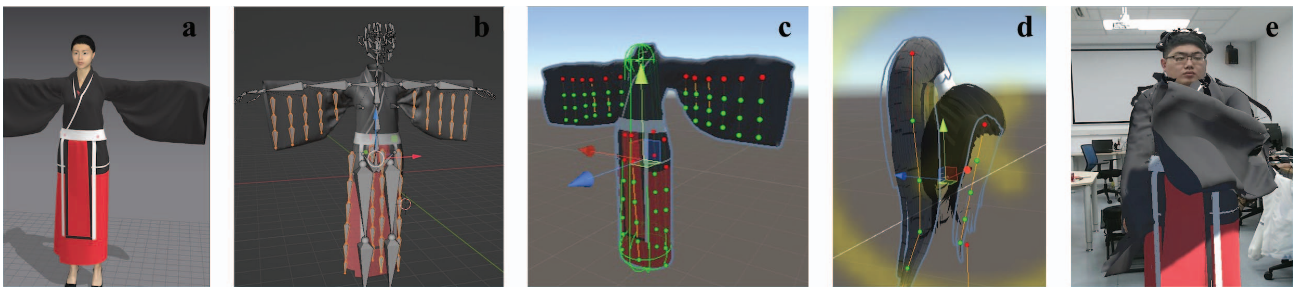

Fig. 1: Creating digital twins of virtual clothing for AR try-on systems: (a) An example model of traditional Chinese costumes in Marvelous Designer; (b) Human bone rigging of the garment model in Blender; (c) Garment model with rigging in Unity; (d) An example model of hair with rigging in Unity; (e) Demonstration of Hanfu AR, an interactive virtual try-on system based on Kinect with realistic cloth simulations.

***Abstract*—We present Hanfu AR, an Augmented Reality (AR) try-on system that presents digital twins of traditional Chinese costumes based on Kinect. The system allows users to virtually try on 3D clothing with real-time interactions and realistic cloth simulation. Specifically, we present an optimized framework that addresses four aspects of the development of digital twins of virtual clothing and try-on systems: calibration, cloth simulation, control, and configuration. Our work contributes to the development of realistic digital twins of virtual clothing and interactive try-on systems. The system can be applied in various areas and has great values in design, culture, education, and marketing. The proposed framework will benefit the future development of digital twins of virtual clothing for applications in the Metaverse.**

***Index Terms*—Digital Twins, Augmented Reality, Virtual Try-On, Kinect**

I. Introduction

In recent years, the retail industry, especially offline sales, has been significantly affected by the epidemic, as people's travel has been greatly reduced. Those who frequently go to shopping malls before the epidemic may turn to online shopping during this time. Although online shopping is convenient for buying clothes, people must carefully check the size information, and it is difficult to intuitively feel the size and wearing effect of the clothes. Even in offline stores, the repetitive process of undressing and dressing can make consumers feel tired and bored.

Hanfu, a type of traditional Chinese costume, is becoming increasingly popular among teenagers and young adults in China. The try-on of Hanfu differs from modern clothes in that many of them are composed of multiple pieces, and it is often larger and heavier. Therefore, sometimes it requires additional assistance to try them on. There are also fewer offline stores that sell traditional clothing, and may not be available in all styles or sizes. This kind of physical try-on of Hanfu has shown some limitations.

Augmented Reality (AR) is the technology that overlays digital content onto the real world [1]. AR try-on systems offer the possibility to enable easy access to a variety of clothing and a convenient try-on experience, both online and offline. We developed the Hanfu AR try-on system, which is interactive, easy-to-use, and supports realistic rendering of cloth simulations (see Fig. 1). Specifically, we demonstrate an optimized framework for the design of digital twins of virtual clothing and the development of try-on systems that addresses four aspects: calibration, cloth simulation, control, and configuration.

Our work has three main contributions. First, we present the system development of Hanfu AR and demonstrate an iterative process that includes the discussion of possible solutions and the justification of choices. Second, we summarize an optimized framework that can be readily adopted by researchers and practitioners interested in creating digital twins of virtual clothing and developing interactive try-on systems. Third, we discuss the application areas of the work and clearly outline the limitations and future research directions.

*Corresponding author: yue.li@xjtlu.edu.cn

979-8-3503-2697-0/23/$31.00 ©2023 IEEE
DOI 10.1109/COMPSAC57700.2023.00225

II. Related Work

A. Digital Twins and Virtual Avatars

Digital twins refer to the digital representations that accurately reflect physical objects or systems [2]. Digital twins have been widely used in various industrial fields, covering a rich array of products and systems [3].

With the continuous development of Virtual Reality (VR) and AR technologies, the virtual world and the real world is gradually being merged. People are envisioning a virtual world that is mapped from the real world, extends the real world, and can interact with the real world, which is known as the Metaverse. It has great potential to provide new 3D environments for people to communicate, shop, study, work and do anything that they would usually do in real life and on the Internet [4]. To achieve this envisioned world, it is important to create digital twins of the real world, and to represent digital identities in the virtual world.

Virtual avatars that embody peoples' digital identity is an essential component of the Metaverse. However, virtual avatars in current VR systems are far from similar to real human beings, and few VR systems support the customization of virtual clothing. Creating digital twins of virtual clothing that has real-time cloth simulations is a significant part to achieve realistic virtual avatars in future Metaverse. However, limited work has been done in this regard.

B. Virtual Try-on Systems

In recent years, wearing Hanfu has become a popular social and cultural phenomenon in China [5]. However, the design of traditional Hanfu is different from modern clothing. It requires considerations of not only the aesthetics, but also the historical and cultural information represented in the clothing. Using 3D simulation technology to design, verify and virtually try on Hanfu will greatly benefit the design process and the retail of Hanfu. Furthermore, with virtual try-on systems, users can quickly and easily try on traditional Chinese costumes of different dynasties, types, colors and styles, which will greatly promote the communication and development of Hanfu culture.

Nowadays, the technology of virtual shoes try-on is relatively mature and has been applied to commercial applications [6], such as the *POIZON* app[1]. The foot size has little influence on the try-on effect, and the shape of the shoes hardly changes when the foot moves. Therefore, it requires the tracking of a static shoe model on the foot only. However, users would expect to see changes in sleeves and skirts as the body moves. Compared to the foot, the human body has different parts thus allowing more complex movements. Therefore, it is more challenging to achieve realistic rendering of clothing in virtual try-on systems.

Li, Zhang and Pan [7] presented a work on virtual try-on. The system takes an image of a user and simulates the try-on effect on the output image. The algorithm extracts information about the user, such as the head, skin color, and body form, and applies it to the try-on image. This study presents a method of image-based virtual try-on, but not real-time virtual try-on.

[1]https://www.poizon.com

Kivisense presents an AR try-on service of clothes [8]. However, the demo shows a simple mapping of a static model of clothing to a human body that has limited movements. There was no simulation of fabric material. Nevertheless, the support of mobile platforms is one of its highlights.

Kim and Forsythe [9] found significant effects of perceived usefulness and perceived entertainment on users' attitudes and intended use of virtual try-on systems. The results suggest that allowing users to try on virtual simulations will create a more compelling online shopping experience and benefit online retailers.

III. System Development and Optimizations

This project aims to implement an AR try-on system to present traditional Chinese costumes (also known as Hanfu). We went through three iterations in the system development and optimization. We achieved basic AR display in the first iteration, in which the 3D model of the costumes can be mapped to a human body. This is similar to most existing AR try-on systems, with limited interactions and cloth simulations. In the second and third iterations, we tried to optimize the control and the cloth simulation respectively. The development work was mainly conducted in Unity. We also tested a series of 3D modeling software and plugins to achieve optimized effects. This section details the system development and optimization process.

A. Iteration 1: Basic AR Display

To achieve the basic AR display of 3D clothing, the first thing is to create the 3D model of traditional Chinese costume. Marvelous Designer is one of the most popular tools that support the design of virtual clothing. Despite that it has a built-in cloth simulation engine, such effects can not be exported together with the model, leading to a static model mapped to the human body when used in Unity development. The incompatibility is a main challenge that lies in the workflow that involves 3D modeling software and game engines.

The display of 3D clothing also requires the calibration of human body. Currently, there are three mainstream 3D camera schemes: stereo vision systems, structured light, and Time of Flight (ToF).

Stereo vision systems use multiple cameras to simulate 3D images. It calculates the distance of objects based on the triangle principle [10]. This approach is widely applied in 3D movies. However, it requires users to wear 3D glasses to obtain the 3D visual effect. It is applicable to wearable AR devices, but not mobile AR (such as smartphones).

With the structured light approach, a structural light is projected with information of fixed shape onto the surface of an object. The camera collects the change of light signals reflected by the object and calculates information, such as the position and depth of the object. It then restores the three-dimensional space. Many mainstream smartphones (e.g. iPhone X), as well as Kinect V1 are equipped with structured light modules [11]. This approach usually has a high depth accuracy, but with high material cost and slow response time. Thus, it is more applied in areas such as 3D scanning, where it is expected to have a high accuracy but more lenient on the response time.

The ToF system is an optical radar system that emits light pulses from the emitter to an object. It measures the distance of the object by calculating the elapsed time of the light pulses from the emitter to the object and back to the receiver in pixel format. Kinect V2 is an example device using this identification approach [12], [13]. This approach is relatively fast in response time, and has low software complexity and good performance in various light conditions. It is widely applied to areas such as games, user interface control, and AR.

As a result of the first iteration, we adopted Kinect V2 with the ToF system and achieved the basic AR display of static garment models that follow users' body movements.

B. Iteration 2: Optimized Control

Limited real-time interaction is allowed in existing try-on systems. Therefore, one of the aims of this work is to optimize the control. By default, Kinect allows a T-pose recognition to calibrate a human body. However, this is not a natural interaction pose. In addition, our initial user research found that changing costumes and adjusting the clothing size are also important parts of user experience with AR try-on systems.

Based on the limitations and user requirements, we optimized the calibration control and implemented a range of control sliders for customized experience with traditional Chinese costumes. Specifically, we changed the body calibration pose from T-pose to a more natural single-hand waving gesture. We also add seven sliders that allow users to change costumes and adjust the garment parameters (see Fig. 2).

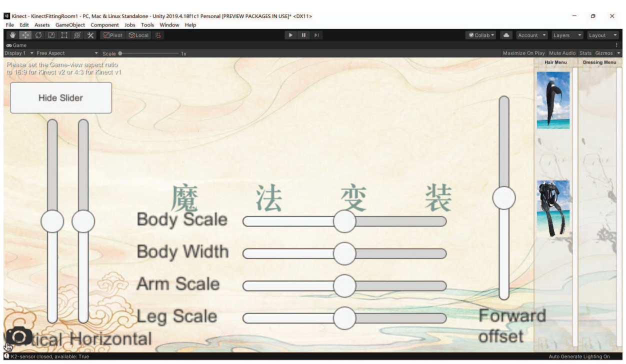

Fig. 2: Slider controls that support the customization of costume size and fitting.

Users could extend the arm to the left or right to change the costume. To customize a costume size, users could move the hand (with the palm facing forward) to a slider position, and pinch the fingers to drag the sliders. The controls support a wide range of customization of the costume, including the garment scale, garment width, arm scale, leg scale, vertical offset, horizontal offset, and forward offset. We also added a 'Hide Slider' button that can hide the slider controls to enable a clear view of the AR try-on effects, and a camera button at the left bottom corner that allow users to take screenshots of the virtual try-on effects.

The second iteration achieved optimized controls in three ways. First, all controls are gesture-based, meaning that they do not depend on the mouse, keyboard, or any other input devices. Second, the control methods adopt natural gestures that are intuitive and easy-to-learn. The gesture controls are similar to controls on smartphones (e.g. swipe, select, and drag and move) and map with users' mental models. Third, it allows a high degree of customization of the garments, and different-body-shape users to obtain the optimal try-on experience.

C. Iteration 3: Optimized Cloth Simulation

The main challenge of creating digital twins of traditional Chinese costumes is the simulation of cloth. Having realistic cloth simulation is a significant factor of user experience in virtual try-on systems. Following the previous two iterations, the garment models were simply bound to the human bones and followed the recognized human body with a static display, while it is not realistic as the textures of the fabric was missing. This is especially important in the simulation of traditional Chinese costumes that often have long sleeves, skirts, and hair. Many 3D modeling software and plugins are equipped with cloth simulation components and plugins, and each has its strengths and limitations. It is worth evaluating which software cloth system to use. Here we discuss some popular options in mainstream software: Marvelous Designer, Blender, and Unity.

Marvelous Designer is one of the most professional development software to create high quality garment models (see Fig. 3). The garment model produced by Marvelous Designer can be exported as FBX model, which is compatible with Unity development. However, its cloth simulation is not compatible with Unity.

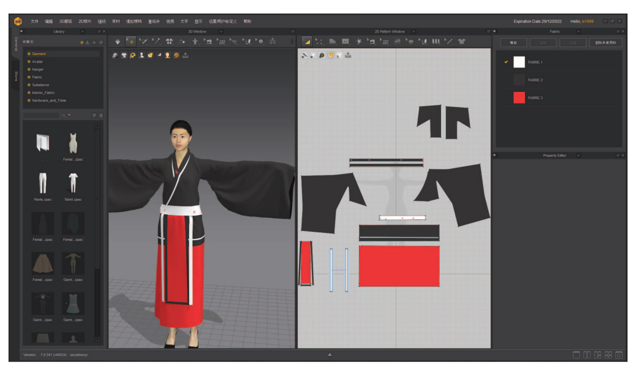

Fig. 3: A 3D model of traditional Chinese costume in Marvelous Designer.

Similarly, Blender has its own cloth simulation system, but cannot be exported together with the garment model either. Nevertheless, the rigging of models could be saved and used in Unity. Therefore in real practice, we found that when the

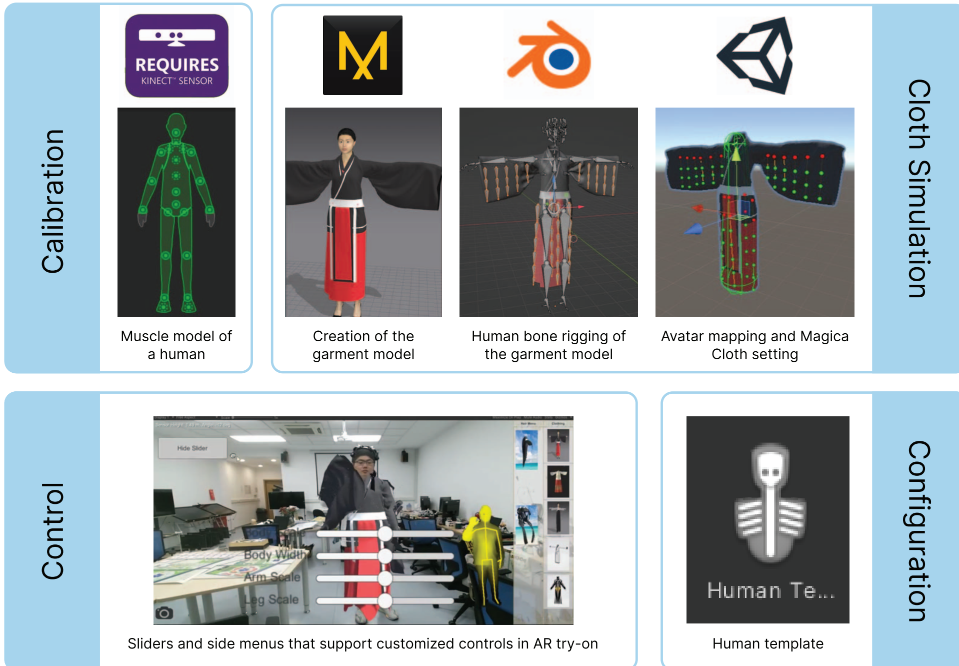

Fig. 4: An optimized framework for developing digital twins of virtual clothing and AR try-on systems.

3D models of garments were saved as T-pose and imported to Blender, they can be aligned with a human bone and the rigging information can be adjusted and saved for use in Unity.

Unity has a Cloth component that can be attached to GameObjects. However, the component only works on a single piece of fabric. Garment models in FBX files have complex fabric settings, in which the effect will violate the realistic fabric physics if the Cloth component in Unity is directly applied to the garment model. Thus, it is challenging to tackle the complex garment model and the single piece of cloth simulation supported in Unity.

We explored some plugins in Unity that aims to solve this issue. Dynamic Bone[2] allows simulation of cloth and hair that moves with a character's bones or joints. We tested this plugin and found that it works well when there is a simple shape attached to a clear joint, such as the hair, tail, and ribbons on an avatar. For cloth simulations with embedded 3D model of the garment and human bone rigging (such as the FBX file exported from Blender), it requires significant manual work to set up the joints and hierarchies of the GameObjects in Unity.

Another plugin we tested was Magica Cloth[3]. It supports similar effects that Dynamic Bone achieved, by mapping the bone with the 3D model. Different from Dynamic Bone, the Magica Cloth component is not restricted to the single chain model structure, but supports the dynamic movements of multiple chains (see Fig. 1c and 1d). The red points indicate the joints, and the green points indicate the components that move along with the joints. Thus, Magica Cloth component works better for long and flowy hair.

The approach provides a new way to simulate cloth in Unity: unlike the Cloth component that is directly applied to a 3D model to simulate the fabrics, it achieves cloth simulation indirectly through the muscle model and the human bone rigging.

In the third iteration, we mainly optimized the cloth simulation of garments and hair based on an optimized workflow that involves the use of Marvelous Designer, Blender, and Magica Cloth Unity. Lessons learned from the system development and the three iterations are summarized into an optimized framework for developing digital twins of virtual clothing and AR try-on systems (see Fig. 4).

IV. Optimized Framework

Creating digital twins of virtual clothing and the developing virtual try-on systems require coordinated efforts in 3D modeling, system development, software testing, as well as user research. There is no single piece of software or platform to-date that can support the entire workflow. Cloth simulations are supported in 3D modeling software, but not in virtual try-on systems that require real-time effects based on users' body movements. We present an optimized framework that addresses four aspects of the development of digital twins of

[2]https://assetstore.unity.com/packages/tools/animation/dynamic-bone-16743

[3]https://assetstore.unity.com/packages/tools/physics/magica-cloth-160144

virtual clothing and try-on systems. This section includes the detailed results and our discussions of the findings.

A. Calibration

Calibration is the first step for users to use an AR try-on system. A depth camera, Kinect V2, is used for the calibration. It uses the ToF method, where the infrared camera projects infrared rays, and the position of the object is calculated according to the flight time of the rays [12], [13].

It was found in the experiment that when using Kinect V2, the recognition accuracy would be greatly reduced and the garment model jitters when users wear pure black clothes. This is a limitation that we observed. It is suggested that users wear bright clothes when using the virtual try-on system.

B. Cloth Simulation

An effective workflow that involves the use of Marvelous Designer, Blender, and Unity is proposed.

First, various styles of virtual clothing can be created using Marvelous Designer, and the designed model in T-pose can be exported as an FBX file.

Furthermore, the file is imported into Blender. The T-pose of the garment model ensures that the sleeves are away from the human bone, so that the automatic weight in Blender could work properly. A human bone is then added, aligned with the garment model and the automatic weight is applied. It generates a garment model with human bone rigging that is ready to be used in Unity.

Third, the FBX file exported from Blender is then imported into Unity, in which the avatar mapping connects the muscle model with the rigging. The Magica Cloth component is then attached to the garment model. As a result, when the Kinect recognizes the muscle model during the AR try-on, the rigging moves with the muscle model, which drives the garment to follow the body movements and achieve the effects of cloth simulation in the try-on system. Cloth simulation in AR try-on systems is one of our main contributions.

C. Control

Effective control and customization capability is another contribution of our work. Common interaction methods in try-on systems include the mouse and keyboard, gamepad, as well as gestures and body movements. Our user research indicated that for a try-on system, users expect controls of changing clothes, adjusting the size of clothes, and taking screenshots. In addition, users prefer to have a mirror-liked screen that clearly shows the try-on effects. This excludes mobile devices such as smartphones, as the display sizes are too limited.

It is inconvenient to use input devices such as the mouse and keyboard and gamepad for virtual try-on system, because users are often away from the display area and expect to be hands-free during try-on process. Thus, natural interactions using gestures and body movements are better options. We implemented the following controls which were found intuitive and easy-to-learn by users:

- Calibration: wave to the camera
- Next costume: extent arm to the right
- Previous costume: extent arm to the right
- A specific costume: palm facing forward, point to the costume, pinch the fingers to select
- Customize size: palm facing forward, point to the slider, pinch the fingers to drag and move the slider
- Take screenshot: palm facing forward, point to the camera button, wait for 3 seconds

For the slider controls, it is necessary for the sliders to be set large enough for users to be able to point and select. As a result, they will take up a large display area. Thus, allowing users to dismiss the sliders is important. We also found that the offset control sliders were rarely used by users. It is likely that there was minimal misalignment, or the offset was not at a level that is noticeable by the users. Thus, keeping the four sliders of size changes will offer a sufficient degree of control.

D. Configuration

Creating digital twins of virtual clothing and applying them to the try-on system requires joint efforts from designers and developers. The proposed framework includes four main steps:

1) Create the garment model in Marvelous Designer and export it as an FBX file;
2) Bind human bones for the garment model in Blender and manually adjust the rigging;
3) Import the Blender FBX file with both the garment model and the human bone rigging into Unity, map Unity muscle models to create avatars and add Magica Cloth component;
4) Develop control methods for customizable AR try-on of virtual clothing in Kinect.

In practice, Blender has a ready-made human bone, but it is not sufficient for the cloth simulation of traditional Chinese costumes with long sleeves and skirts. Thus, designers and developers need to manually edit the rigging of these parts.

As for the avatar mapping step in Unity, the mapping of the muscle model and the human bone rigging can be automatically achieved. Given that the same set of bones is used in Blender for rigging, the names and relative repositories of bones are the same for different garment models. Therefore, we implemented a script that can automatically complete the process of avatar mapping in Unity without any manual effort. We saved the character mapping data as a Human Template (HT) file (*.ht), which is reused to map other garment models directly in Unity to produce new avatars without manual adjustments This significantly improves the configuration of the try-on system and contributes to the scalability of the system when adding new garments in the future.

V. Discussion

A. Application Areas

The current work can be applied in various areas. For example, museums can set up an interactive area for visitors to try on traditional garments and take pictures. This kind of active participation in cultural activities will strengthen visitors' memory and their learning about the histories and cultural values. In addition, virtual try-on systems can be used in shopping malls, so that customers can get a quick glance at a variety of clothing without having to take them off and try them on for multiple times. Quick sketches of design ideas and visualization of the effects in try-on systems also benefit the fashion industry in ideation activities.

Creating digital twins of virtual clothing is meaningful to the past, present, and future: the wide range of application areas will increase the accessibility of clothing in the past, improve shopping experience with clothing in season, and allow designers to explore more possibilities of clothing in the future. In the meantime, since the try-on systems require cameras to capture body movements, ethical considerations are significant when the system is applied in public areas. It is necessary to obtain permissions and strengthen network security to ensure user privacy.

B. Limitations and Future Work

There are some limitations in our work. The first limitation lies in the hardware and software. We used Kinect as the main hardware device and Unity as the main software development platform. Despite that Kinect has great support in rendering 3D images for the AR display, it often works together with Xbox 360 and does not have its own processor. Thus, its processing speed and accuracy are limited [14]. Moreover, some underlying logic in Kinect cannot be optimized as they are not open-sourced. Unity is widely used by independent developers and teams, and our development focused on workflows and frameworks that are compatible with Unity development. There are other options such as the Unreal game engine, which also supports realistic rendering of 3D graphics. However, this is not within the scope of the current work.

The current system is also limited in the accessibility of the controls and evaluations. Since the controls we implemented in the try-on system were based on gestures and body movements, the system might not be friendly to the physically impaired users. More accessible control approaches, such as voice controls and eye-based controls could be considered in the future work. We have involved several stakeholders in the development process, during which we constantly sought for their suggestions. Formal investigations of the system usability and user experience are part of the future work.

The configuration part of Unity avatar mapping was optimized and automated using a human template file. However, the previous steps of model editing are not automated. This is an area of improvement in future work. In addition, the primary focus of the current AR try-on system was the realistic visual perceptions. However, real try-on experience in shopping malls provides more than this. It also involved the sense of touch and even warmth. This could be an interesting research direction of virtual try-on systems in the future.

VI. Conclusion

In this paper, we present an optimized framework for the design of digital twins of virtual clothing and the development of an AR try-on system. Motivated by the limitations in current try-on systems and the user requirements, we underwent three iterations that achieved basic AR display and optimized the controls and cloth simulation of traditional Chinese costumes. The results show that the Time-of-Flight method based on Kinect could support the calibration and tracking of the human body in AR display. The cloth simulation in AR could be achieved with the creation of garment model in Marvelous Designer, human bone rigging in Blender, and avatar mapping and Magics Cloth setting in Unity. We also optimized the controls to support interactive AR try-on experience with natural gesture controls. Our work can be widely used in culture and education, retail and marketing, and fashion design, among other fields. In terms of methodology, the proposed framework provides guidance for the design of interactive and realistic digital twins of virtual clothing for use in the future Metaverse.

Acknowledgements

We would like to thank our stakeholders for the valuable suggestions. This work is supported by the National Natural Science Foundation of China (62207022), Natural Science Foundation of the Jiangsu Higher Education Institutions of China (22KJB520038), and Suzhou Municipal Key Laboratory for Intelligent Virtual Engineering (SZS2022004).

References

[1] R. T. Azuma, "A survey of augmented reality," *Presence: teleoperators & virtual environments*, vol. 6, no. 4, pp. 355–385, 1997.
[2] A. El Saddik, "Digital twins: The convergence of multimedia technologies," *IEEE multimedia*, vol. 25, no. 2, pp. 87–92, 2018.
[3] X. Zheng, J. Lu, and D. Kiritsis, "The emergence of cognitive digital twin: vision, challenges and opportunities." *International Journal of Production Research*, vol. 60, no. 24, pp. 7610 – 7632, 2022.
[4] T. Rahaman, "Into the metaverse - perspectives on a new reality." *Medical reference services quarterly*, vol. 41, no. 3, pp. 330 – 337, 2022.
[5] W. Xinyi, F. Colbert, and R. Legoux, "From niche interest to fashion trend: Hanfu clothing as a rising industry in china." *International Journal of Arts Management*, vol. 23, no. 1, pp. 79 – 89, 2020.
[6] Q. Jiang, C. Gu, Y. Feng, W. Wei, and W.-C. Tsai, "Study on the continuance intention in using virtual shoe-try-on function in mobile online shopping." *Kybernetes*, 2022.
[7] J. Li, M.-M. Zhang, and Z.-G. Pan, "Virtual try-on by replacing the person in image," *Journal of Computer-Aided Design and Computer Graphics*, vol. 27, no. 9, pp. 1694–1700, 1 2015.
[8] Kivisense. [Online]. Available: https://www.kivisense.com/#usecases
[9] J. Kim and S. Forsythe, "Adoption of virtual try-on technology for online apparel shopping." *Journal of Interactive Marketing*, vol. 22, no. 2, pp. 45 – 59, 2008.
[10] A. O'Riordan, T. Newe, G. Dooly, and D. Toal, "Stereo vision sensing: Review of existing systems," in *2018 12th International Conference on Sensing Technology (ICST)*, 2018, pp. 178–184.
[11] R. M. Ruiz, M. T. M. Torres, and P. S. Allegue, "Comparative analysis between the main 3d scanning techniques: Photogrammetry, terrestrial laser scanner, and structured light scanner in religious imagery: The case of the holy christ of the blood," *ACM Journal on Computing and Cultural Heritage (JOCCH)*, vol. 15, no. 1, pp. 1–23, 2021.
[12] S. Gao, L. Fang, and X. Cui, "Research on tof camera-based guided binocular fusion technology." *2021 IEEE 3rd International Conference on Frontiers Technology of Information and Computer (ICFTIC)*, pp. 767 – 772, 2021.
[13] Kinect. [Online]. Available: https://docs.microsoft.com/en-us/windows/apps/design/devices/kinect-for-windows
[14] Y.-I. Yang, C.-K. Yang, and C.-H. Chu, "A virtual try-on system in augmented reality using rgb-d cameras for footwear personalization," *Journal of Manufacturing Systems*, vol. 33, no. 4, pp. 690–698, 2014.