An Interactive AR-Based Virtual Try-on System Using Personalized Avatars: Augmented Walking and Social Fitme

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***Abstract* — E-commerce websites offer the convenience to consumers to purchase clothes online. However, they have difficulties imagining how they will look like. To address this problem, we propose a holographic 3D virtual try-on system that provides users a novel experience where they can view garments fitted onto their own personalized virtual body. The garment models are generated from garment images obtained from online shopping websites. Users can animate their dressed virtual body in a real-life scene in augmented reality. We also propose Social Fitme, which provides multiple users an intuitive sharing experience with others. Users can try on clothes with their friends and communicate with each other, thereby giving them the opportunity to make more confident decisions. We conducted a user study to compare our proposed system with an image-only shopping system and validate its effectiveness. We found that Social Fitme can greatly improve the shopping pleasure of users and provide them a more engaging and effective shopping experience. Interactions between users can help them explore new styles, enhance their relationships, and strengthen their social connections.**

Keywords* — *augmented reality; virtual try-on; personalized avatar; virtual fitting; garment modeling; social interaction; shared experience; augmented walking.

I. INTRODUCTION

With the continuous development of the e-commerce technology, the number of consumers purchasing clothes online is increasing. Consumers usually desire to try on garments to assess if the clothes are suitable before purchasing. However, when shopping online, they cannot try them on. Consequently, they may worry how well the clothes will fit on their own body. Furthermore, it is difficult for them to imagine how they will look like with various postures (e.g., standing, walking and posing) or in different settings.

To address these problems, we have proposed a 3D virtual try-on (VTO) system using personalized models [1] (Figure 1).

(a) We generate virtual models of users based on their own body and face information.

(b) We gather some garment information and achieve 3D garment visualization using Cloth-Weaver [2].

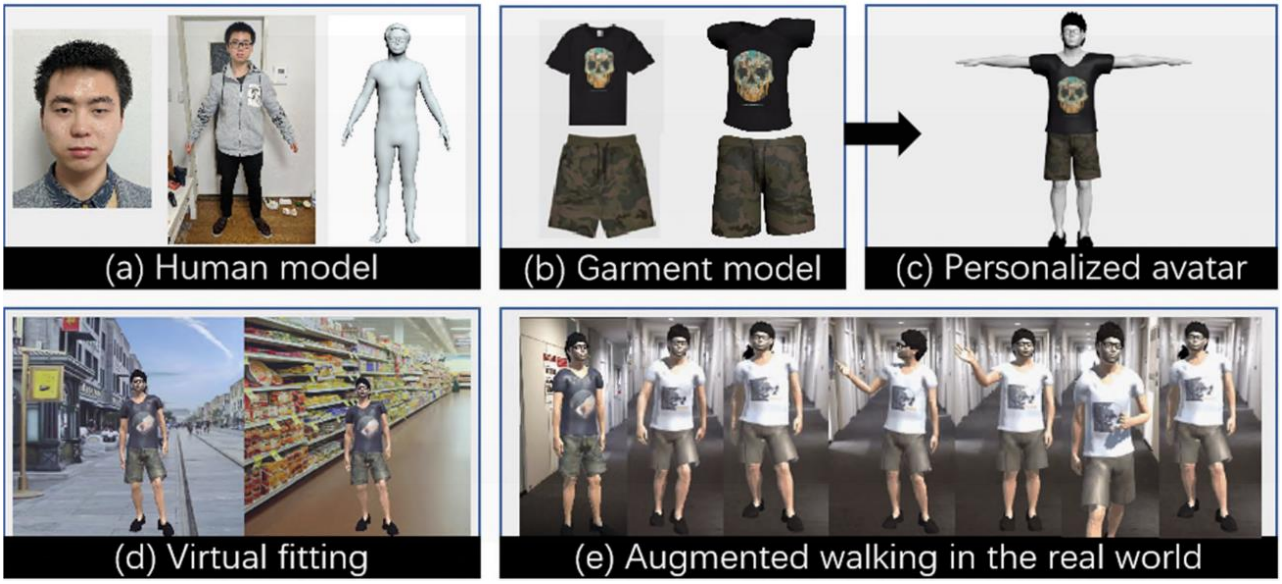

Figure 1. Our system allows users to view virtual garment fitted onto personalized body models and animate them in real-life scene

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(c) We customize the garment model for each user and match it to their personalized virtual models.

(d) We enable users to view their own personalized body model fitted with virtual garment.

(e) We enable these models be visualized in a real-life scene together with animated motions.

To determine the user's acceptability, we conducted a user study to evaluate the value and convenience of our system. We also propose Social Fitme, which allows multiple users to virtually fit garments together (Figure 2). Our system reduces the gap between offline shopping and online shopping. It enhances the social experience of online shopping by allowing users to experience the pleasure of physical shopping with friends, choose clothes for each other, and get quick feedback in real-time. The aim of the system is to improve the user experience of online shopping by enabling social interaction between users while engaging with a more personalized VTO system.

We introduce two advanced features of online shopping in our proposed VTO system as the main contributions of this study:

1) A fully personalized VTO system that enables users to view virtual garments interactively and immersively in 360° as well as check their garment on a personalized virtual body augmented with human-like motion in the real-world. Users can try on clothes directly and quickly view the appearance of their dressed body.

2) A socially interactive VTO system that supports an intuitive sharing experience for users. Users can experience social interactions during the VTO process, such as sharing their dynamic dressed virtual body with each other. Social Fitme strengthens the social connections between users when shopping online. Interactions between users can help them make more confident decisions and explore new clothing styles.

The rest of the paper is organized as follows. In Section Ⅱ, a brief review of previous research on VTO, garment modeling and virtual avatar is presented. In Section Ⅲ, we describe the system design, including human model personalization, garment model generation and 3D VTO system. In Section Ⅳ, Social Fitme, which is a socially interactive VTO system is described. In Section Ⅴ, we present our evaluation result. In Section Ⅵ, conclusion and future works are described.

II. Related Work

In this section, we will describe the related work. Related work on VTO, Garment modeling, Virtual avatar, Personalization of VTOs, and Virtual avatar in social augmentation is described in this order.

A. VTO

Earlier works on VTO are mostly conducted in computer graphics [3][4][5]. Previous works focused on two types of VTO: 2D overlay VTO and 3D VTO.

2D overlay VTO:

Hilsmann et al. [6] retextured garment overlay for real-time visualization of garments in a virtual mirror environment. Yamada et al. [7] proposed a method of reshaping the garment image based on human body shapes to make fitting more realistic. However, similar to many other retexturing approaches, it operates only in 2D without using 3D information in any way, which does not allow users to view their virtual self from arbitrary viewpoints.

3D VTO:

3D garment models perform precise garment simulation rather than just 2D overlays. Protopsaltou et al. [8] created a virtual dressing room, where customers can view garments fitted onto their virtual body. Li et al. [9] proposed a multi-part 3D garment model reconstruction method to generate virtual garments for virtual fitting on virtual avatars.

Recently, VTO has been combined with augmented reality (AR) or virtual reality (VR) technologies to provide consumers a more realistic try-on experience. Consumers can get a better sense of how they will look like when wearing the products. Several fashion firms, including Uniqlo

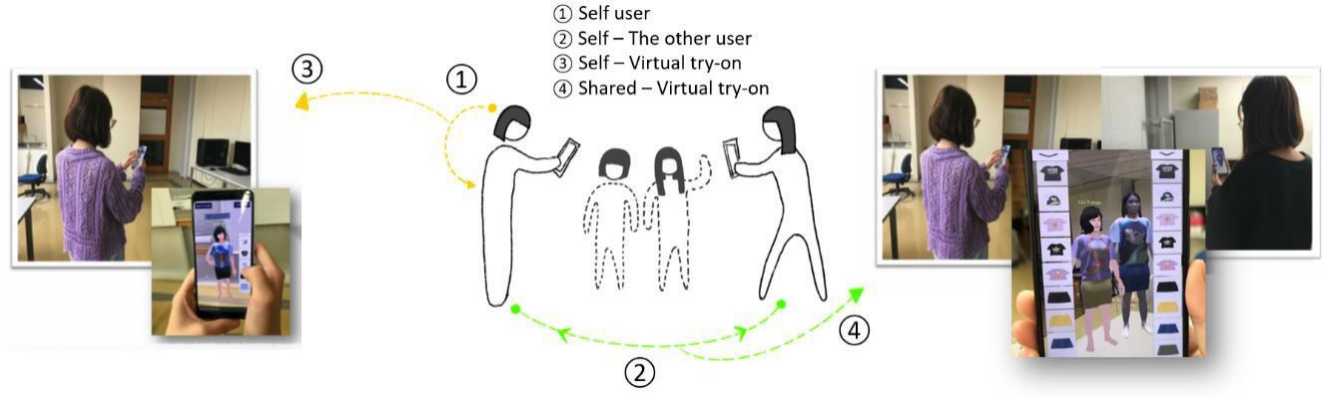

Figure 2. Social Fitme, an AR-based try-on system for multiple users to share their fitting experience together. Users can virtually try- on clothes using a mobile device and view their personalized virtual avatar in motion in the real world. They can speak to each other and give fashion advice in real-time when using the system

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and Gap, have utilized the AR technology in the form of a mobile applications [10]. Using the VR technology, consumers can feel like they are physically in a virtual fitting room. Several fashion retailers have provided this kind of shopping experience, such as Alibaba and Dior.

B. Garment modeling

Unlike 2D images, a 3D garment model can be used to perform precise garment simulation. Most garment modeling research focuses on 3D garments for a virtual character. Some garment-retargeting methods transform garment designs from one character to another. For example, Pons-Moll et al. introduced a system using a multi-part 3D model of clothed bodies for clothing extraction and retargeting the clothing to new body shapes [11]. Pattern-based methods simulate the garment creation process in real life, while garment modeling tools, such as Marvelous Designer [12], offer garment modeling and editing of pattern design. Pattern-based methods require professional knowledge of garment design and are difficult for non-experts. To address the problem of digitizing garments, Zhou et al. created virtual garments from a single image [13]. Chen et al. captured real garments using a depth camera and built a coarse shape from its raw RGBD sequence using the RGB color information and depth information [14].

C. Virtual avatar

Most VTO systems provide a virtual fitting experience on a default virtual avatar, rather than one generated from users' own body [15]. The default virtual avatar can be modified by users based on individual preferences and can be personalized by uploading their facial images [16][17]. This type of virtual avatar cannot reflect the true body shape of consumers.

The absence of "true fit" may disappoint customers when shopping online. For our proposed system, we create virtual a personalized model for each user, which can reflect their body shape and facial appearance. This will make their try-on experience more accurate and engaging, thus increasing their confidence when making purchasing decisions on garments online.

D. Personalization of VTOs

Depending on the avatar's level of personalization, the avatar representing the user may or may not provide a real sense of self. According to the avatar's similarity to the user, virtual try-on systems can be divided into two levels [18]:

1) ***Non-personalized VTO:***

Some VTO experiences are based on a default virtual avatar, not generated from the user's own body [19][20]. The lack of precision in describing users and products reduces VTO experience of users.

2) ***Personalized VTO:***

Personalized VTO enables a more realistic user experience where the virtual avatars can mirror their actual looks and fit the clothes on the virtual self [21][22][23]. The virtual avatar is customized with personal features (face, height, weight, and body shape). Kim et al. researched the perceived usefulness, enjoyment, and ease of use of the personalized VTO [20]; Merle et al. argued that the personalized VTO can lead to more positive consumer perceptions than the non-personalized VTO and provide a higher self-congruity with the virtual model [18].

E. Virtual avatar in social augmentation

Early research has shown that a virtual avatar represented by a graphical persona in a virtual social environment can create an illusion for users that they are in the environment and co-present with their companions [24][25][26]. Roth et al. found that virtual avatars that can perform daily social interactions can increase social presence in a multi-user environment and enhance user experience [27]. For co-located social experience, Lankes et al. investigated the effects of avatars and verbal communication on co-presence in a cooperative game [28].

In summary, we found that there is a lack of research exploring the dynamic VTO experience with personalized motions. In addition, the social feature is an important factor of dress fitting that has been ignored in previous VTO systems. Our proposed AR-based try-on system provides multiple users an intuitive sharing experience, allowing them to view their dressed body with personalized human-like motions augmented in the real world and share their outfits with others.

III. 3D VTO

Our 3D VTO system involves human model personalization, garment model generation, and 3D VTO.

Figure 3 presents an overview of our proposed system. This system uses three elements as input: a single face image with a full-frontal face, a short video of the user's full body, and a 2D garment image from online shopping websites. The procedure can be described as follows:

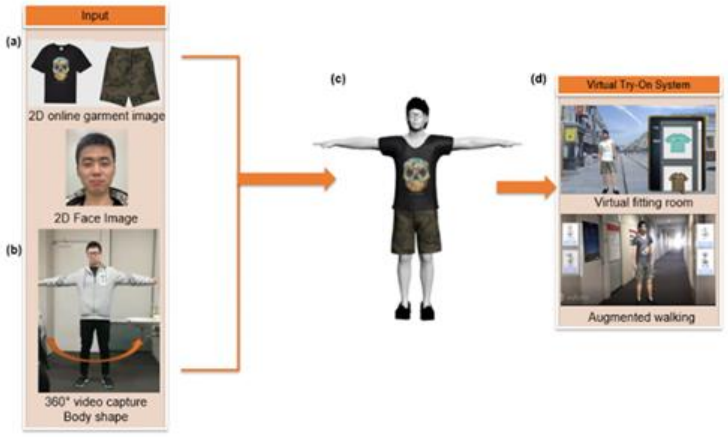

Figure 3. System Overview

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Figure 4. Generate 3D garment model based on the information from shopping website

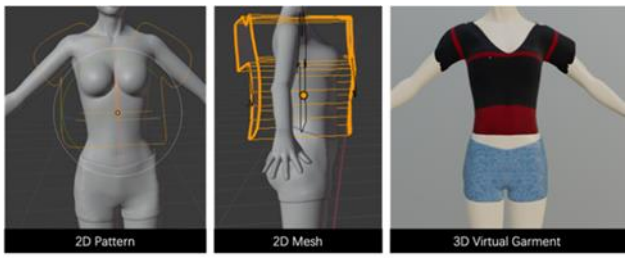

Figure 5. 2D patterns creation and positioning around generic body

(a) Mapping the 2D garment image into the 3D garment model templates and generating the 3D garment model based on online images.

(b) Generating the 3D human model based on the face image and recorded video.

(c) Matching the 3D garment model to the human model.

(d) Users choose different clothes to try on. Users can change the pose in VR fitting room. They can also see their augmented walking in AR environment.

A. Human model personalization

Owing to the lack of physical fitting in online shopping, a gap between the actual and perceived body size can exist, which may make it difficult for consumers to examine the true fit on their own body and influence their purchase selection while shopping online. Therefore, the virtual human body should have an appropriate 3D representation corresponding to the real user's human body shape and facial features.

This will give a better representation of the user and allows for a more accurate clothes fitting, as well as for virtual human body animation. We create human body models based on Alldieck's study [29] and generate face models based on Deng's method [30]. Moreover, a hair model library is prepared, and the most similar hair model is matched to the face model we generated.

B. Garment model generation

To provide users with better garment product visualization, we allow users to view garments from various angles and directions when users are shopping online. Our approach uses garment image information from existing shopping websites (e.g., H&M [31] and Zara [32]) to create a virtual garment library. Textures are extracted from the garment image and mapped onto the 3D garment model. The final 3D garment is shown in Figure 4. We mainly focus on these two parts: garment model templates used in our system and 3D modeling and texturing approaches.

Figure 6. Some 3D garment templates provided for users

3D garment model templates

Garments are created using the traditional 2D pattern approach. We build several 3D templates of virtual garment models for the personalized human model using Cloth Weaver, which is a Blender template library. It allows simulating the methods of traditional garment designs. The 2D pattern is discretized into a triangular mesh. Next, we design and modify the 2D pattern, and then use the reference line to automatically fit the flat pattern to the corresponding part of the body (Figure 5). These are used as the basis for creating a variety of garment models (Figure 6). We simulated several types of clothing for female and male bodies. For females, we prepared them with long sleeves, T-shirt, long pants, dress and skirt for fitting. For males, we prepared them with T-shirts, long sleeves and half pants for fitting.

Texture mapping

We collected garment images from existing shopping websites (H&M, ZARA, etc.) and mapped these clothes images to generated 3D garment model templates (Figure 7). We segmented different parts of the garment from a single garment image. The segmented clothes can be divided into three main parts: left sleeves, right sleeves, and the front of clothes. The 3D mesh of a generated garment template can be extended into a 2D reference mesh in 3ds Max [33]. To map the web garment image into a 3D virtual garment template, we

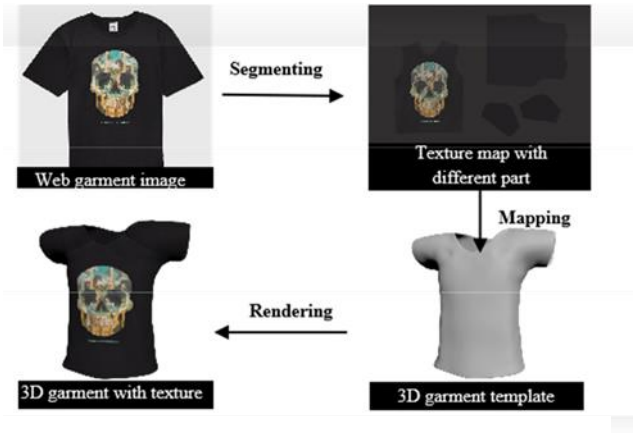

Figure 7. Mapping Web garment image to generated 3D garment templates

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Figure 8. Garment model library for female and male

map the different segmentation parts from the garment image to its corresponding parts on the garment template.

In this way, we can generate a 3D garment model with texture. The garment can be customized in various ways to match the desired design. The most obvious change is the customization of appearance and color, which is achieved by modifying the texture of the cloth. Therefore, we collected garment images from online shopping websites as textures and created a garment model library for users (Figure 8).

C. 3D VTO

We gathered various garment information from online websites to enhance the online shopping experience of users. Our system was developed using Unity3D [34] on Windows 10 and we deployed our system on Android smartphones. The 3D VTO system consists of two parts: virtual fitting and augmented walking.

Virtual fitting

Virtual reality relies on an entirely digital environment that can provide an immersive and interactive shopping experience for users. We prepared a variety of fitting scenes for users, such as on the street, in the office and at the supermarket. Users can view the virtual garment based on the different virtual scenes, giving them an idea of how they will look like for various occasions or purposes (Figure 9).

Augmented walking

Normally, when users shop at physical (offline) stores, they often check the attributes of clothes through various motions, such as twisting the body or raising the arm to help confirm the suitability of the clothes. However, when shopping online, users cannot visualize the details of the garment. Compared to the offline try-on experience, the traditional online shopping purchasing environment lacks the capability for users to try-on garments on their own body and check whether the clothes fit on them under various postures. Therefore, we propose a dynamically interactive method that allows users to animate their dressed human body in 360°and

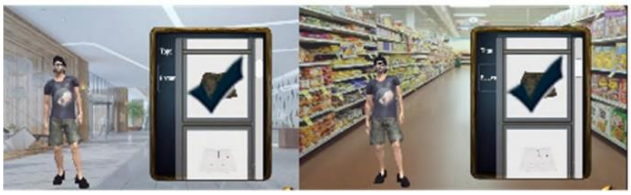

Figure 9. Fitting scenes

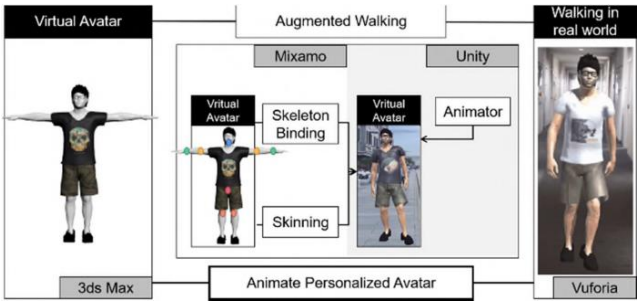

Figure 10. Implementation of augmented walking

enables them to view their virtual body walking in the real-life scene.

The implementation of the augmented walking framework aims to animate the personalized avatar of users in the real world. Figure 10 depicts the workflow of animating the personalized virtual avatar in the real world, which can be described as follows.

1) **Personalized virtual avatar.** We integrate the virtual human model and clothes model in 3ds Max and export the virtual avatar as .fbx file.
2) **Skeleton binding and Skinning.** We upload the personalized virtual avatar to Mixamo [35], which is a web-based service for creating 3D animation of human models. We bind the skeleton to the virtual avatar and skin it using Mixamo.
3) **Animate virtual avatar.** To attach the animation to a personalized avatar, we use the animator controller in Unity [36] to control the virtual avatar and perform various animation.
4) **Augmented walking in the real world.** We realize the augmented walking using Vuforia Augmented Reality SDK [37].

We fitted our generated human model with garment models and created walking and posing animations, as illustrated in Figure 11. Using Mixamo, the motions we generated are very lifelike actions, such as waving/shaking hands, walking, sitting, and turning around.

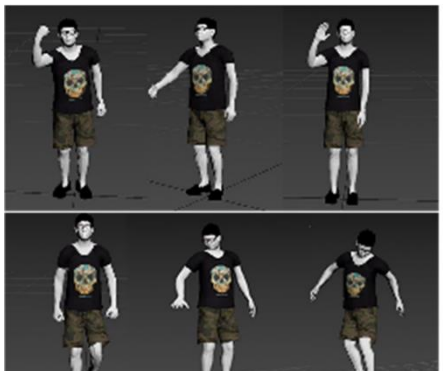

Figure 11. Postures of personalized human model

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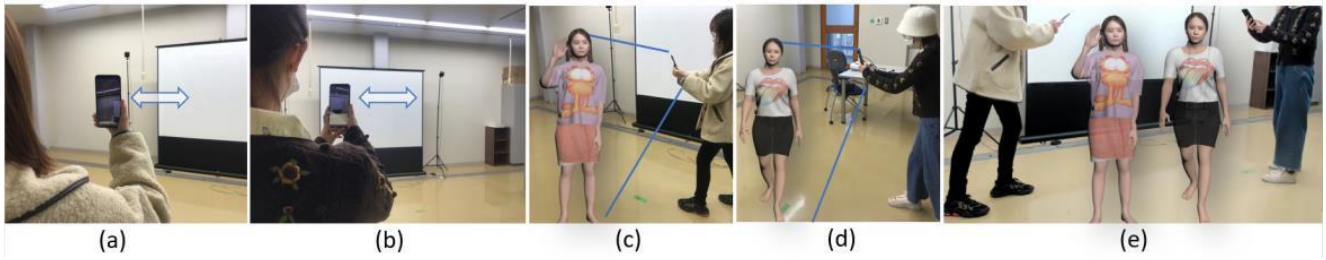

Figure 12. The workflow of Social Fitme

IV. SOCIAL FITME: SHARED VTO EXPERIENCE

AR applications can enable social interactions among users. They can interact with the virtual content while engaging in normal communication in the real world. So far, there is a lack of research on applying AR for VTO.

Social Fitme is an AR mobile application that supports interactive social sharing of VTO experience for multiple online shopping users (Figure 12). Based on online shopping websites, 3D garments are generated, which provide users a more realistic try-on.

Users can first create a fitting room by scanning the ground (a, b), and animate their virtual avatars in the real environment (c). Other co-located users can join in the same fitting room and can be represented as virtual avatars located in the same position and orientation in the same physical environment (d). Users can interact with the virtual avatar, virtually try garments on, communicate with each other and give fashion advice (e).

To provide users a more engaging VTO experience, Social Fitme allows users to socially share their intuitive VTO experience with others, enabling them to get quick feedback as well. Users can both try on clothes on their own body or on other user's body. They can also help each other make decisions and find the best match for each other (Figure 13).

Our system was developed using Unity3D on Windows 10 and deployed on Android smartphones. The implementation of our system consists of the following three parts:

Human model personalization. We personalized theappearance of users based on their face image and full-body images. The 3D face model was generated using 3D avatar SDK [38], whereas the body model was built by 3DLook [39]. They were then combined into a 3D human model.

Motion capture. To gather individual movements of users, we used Microsoft Kinect V2 depth sensor [40] to record postures and user movements and create their own animation library for our system. To convert the captured motion captured data into animation, we used a Unity plugin, Cinema-Mocap [41], which is a marker-less motion capture solution for Unity to create customized animations for users. As the movement captured by Kinect V2 depth sensor is somewhat jittery, we edited and smoothed the animation frame-by-frame using Maya software [42], which is a 3D computer animation, modeling, simulation, and rendering program.

Shared VTO experience. To share the VTO experience with co-located users, we used ARCloud Anchors API from Google. ARCore [43] connects to its ARCore cloud anchor service to host and resolve anchors. The hosting and resolution of an anchor can be deployed on multiple devices through an effective network connection.

Figure 13. Our system provides an intuitive sharing virtual try-on experience for users

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TABLE I. QUSTIONNAIRE AND MEASRUEMENT ITEMS

Items	Statements
Enjoyment	**a.** Using the system, shopping experience was enjoyable for me.
Convenience	**b.** I can get a sense of how the outfit might look for the various occasions. **c.** I can get a sense of how I look wearing these clothes.
Augmented Walking	**d.** Seeing a model of me walking in the real-world enhanced my shopping experience. **e.** Having a model walking in a real environment helps me understand more about the appearance of the clothes.
User Behavior	**f.** I want to use this system when I buy some clothes online in the future.

V. EVALUATION

We carried out two user studies. i.e., user study 1 and user study 2, to evaluate our system. The objective of user study 1 is to assess whether our 3D VTO system can enhance the online shopping experience of users. The objective of user study 2 is to evaluate the effectiveness of the system and interactions designed to support the sharing of VTO experience in AR.

A. User study 1

1) Participants

A total of 10 college students participated in both condition 1 (VTO condition) and condition 2 (image-only condition). College students aged 18–30 years are usually targeted by AR/VR applications, as they are more likely to try new technologies and they are proactive in online shopping for fashion products. Hence, we invited N=10 participants (7 males and 3 females) with an average age of 22.5 years to complete our evaluation.

2) Evaluation design

We conducted an initial experiment to evaluate our system. The objective was to assess whether our 3D VTO system could enhance the online shopping experience of users, thereby helping them make better purchasing decisions. To investigate the users' attitudes toward the typical online shopping and 3D VTO with augmented walking, we conducted an experimental study with the following two conditions.

a) VTO condition: simulation of shopping experience using our 3D VTO system.
b) Image-only condition: simulation of typical online shopping experience using only images of garments online.

We hypothesized that the former condition would lead to a higher rating than the latter.

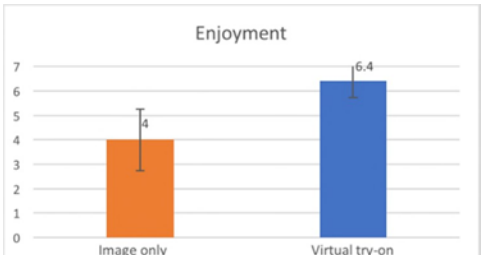

Figure 14. Participants rated their Experiences more enjoyable in the virtual try-on condition

We personalized the human model of each participant based on their 2D face image and 360° body videos. Each participant simulated the shopping experience with two different conditions. The order of the conditions was randomized. After each task, the participants were asked to rate their experience (from 1 "strongly disagree" to 7 "strongly agree") in our questionnaire, indicated on a 7-point Likert scale. At the end of the experiment, we interviewed the participants to gather their preferences and open-ended feedback.

We measured enjoyment, convenience, and user behavior for the two conditions. We also analyzed whether the augmented motion in the real-life scene enhances the users' shopping experience. The questionnaire and measurement items are presented in Table I.

3) Results

We separated the result into two sections: analysis of the rating from questionnaires and thematic analysis of the participants' comments.

We analyzed the result in terms of user enjoyment, convenience, augmented walking, and user behavior.

Enjoyment. As Figure 14 shows, we found a significant effect on the participants' shopping enjoyment. A repeated measures t-test revealed a statistically significant difference between the various conditions ($p<0.01$). The participants rated the enjoyment significantly higher in the VTO condition.

Convenience. We analyzed the user convenience through the two statements below:

A. "I can get a sense of how the outfit may look for various occasions." We found that the participants rated the VTO ($p<0.01$) significantly higher than the other condition (Figure 15).

B. "I can get a sense of how I look wearing the clothes." We also found that participants rated the virtual try-on condition ($p<0.01$) significantly higher, meaning that it gave users a better feeling for how these clothes might look like on their body (Figure 16).

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Figure 15. Participants rated their Experiences more enjoyable in the virtual try-on condition

Figure 16. Participants rated that virtual try-on condition gave users a better feel for how these clothes look like on their body

Augmented walking. To understand whether the 3D VTO system within the AR scene enhances the user experience, we prepared two statements:

a. "Seeing a model of myself walking in the real-world enhanced my shopping experience." Figure 17 summarizes the of participants' opinions of VTO condition.

b. "Having a model walking in a real environment helps me understand more about the appearance of the clothes." Figure 18 summarizes the participants' opinions of the VTO condition.

In summary, all participants have the same opinion that augmented walking can enhance their shopping experience. Of the 10 participants, 9 rated that the virtual model walking in the real environment helps them understand more about the appearance of the clothes. One of the main reasons given is that the real environment is very realistic, which helps them to view the appearance of the garment model. Moreover, the virtual models walking in the real-life scene are very interesting and can improve the participants' enjoyment of the online shopping process. At the same time, augmented walking can also provide a better 3D visualization for users.

The dynamic fitting display can show the shape of the clothes when they are in motion and increases the number of clothes attributes that can be observed.

User behavior. All participants preferred the VTO condition for both enjoyment and convenience. We also analyzed the

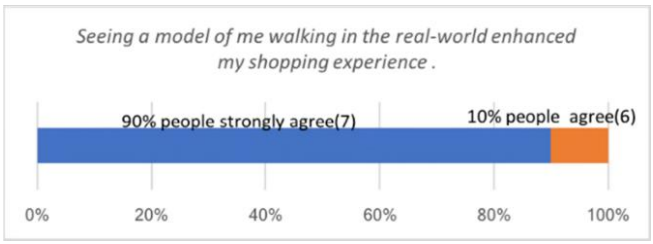

Figure 17. All participants agree that seeing own model in the real-world enhanced their shopping experience. 9 out of 10 participants strongly agree with it

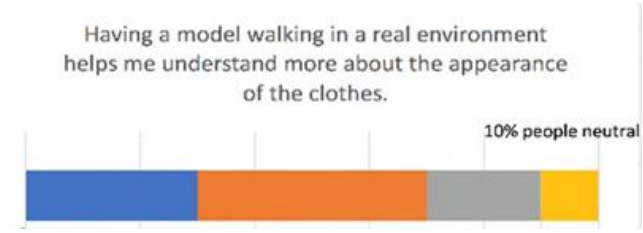

Figure 18. Most participants agree that the model walking in the real environment helps them understand more about the appearance of the clothes

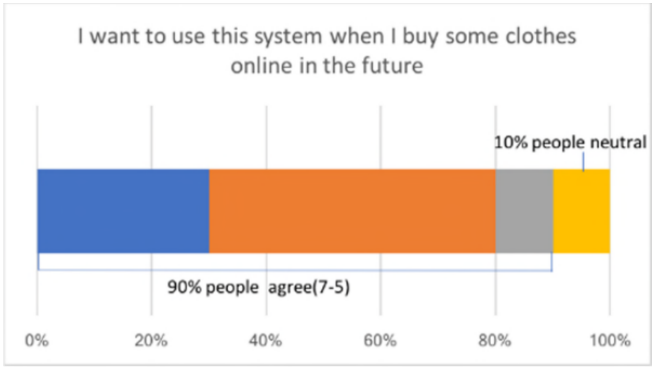

Figure 19. Most participants want to use this system when they buy some clothes online in future

user preference on whether they want to use the VTO system in the future or not. The results indicated that 9 out of 10 participants wanted to use this system in the future (Figure 19).

4) Qualitative results

At the end of the experiment, open-ended feedback was sought from the participants, and a thematic analysis was performed on their responses and their impression of using our 3D VTO system.

Most participants thought that the virtual avatar with augmented walking in the real world offers them a sense of wearing clothes on their own body, which can provide them with a better understanding of the detail of the clothes. Moreover, augmented walking allows them to visualize their personalized model in the real world, increasing their shopping enjoyment. P6 mentioned that the augmented walking makes them feel like they are looking into a mirror. P7 said that augmented walking in the real world can help

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them observe more details of clothes.

Most participants thought that our system is interesting. Our system can enhance their experience and narrow their selections when shopping online. For instance, P1 mentioned, "Shopping online is difficult because the model's body shape is pretty, while people in real life don't have such a perfect body. This system shows how the clothes look like on my body in the real world, which gives me confidence when buying clothes." Similar comments were received from P3 and P4.

Furthermore, the 3D VTO system provides users outfit ideas and more clothing information to users. P3 thinks that the 3D virtual system provides various virtual scenes to help users in selecting clothes, especially for special occasions. P6 mentioned that the 3D garment model allows him to see himself wearing clothes in 360° and obtain additional clothing information than just looking in a mirror. P7 said that the virtual model walking in the real world may help them in checking how they will look like in the real wearing conditions.

We also received comments about future improvement. P3 suggested that the material of clothes could be improved to look more like a real fabric, and P9 thought that it would be better to use motion capture to simulate real movements of users moving in the real world. The free comments from participants are summarized in Table Ⅱ.

B. User study 2

1) Participants

We recruited 12 participants (6 females and 6 males) aged between 20–25 years old. We selected participants from this demographic because they are usually the target users of AR/VR applications, since they are more likely to try new technologies and are proactive in online shopping for fashion products. We gathered their relationship with their partner by the inclusion of community in self-scale (IOS) [44].

TABLE II. SUMMARY OF FREE COMMENT

Keyword	Conclusion andComments
Augmented walking	**Judging of fitting:** Wearing clothes doing some activities in the real world provides users with better understanding of the detail of clothes, which allows to better judge of fitting. **Humanoid motion:** Using motion capture technology to capture user's movement may offer users a better sense of "real me".
Garment model	**Information visualization:** The 3D virtual try-on system gives users outfit ideas and provides more clothing information to users (muti-direction and muti-angle). **Realistic garment:** Garment material can be more like real fabric.
Shopping experience	The 3D virtual try-on system can narrow users' selections of clothes and increase their purchase confidence. Increases the enjoyment of shopping experience.

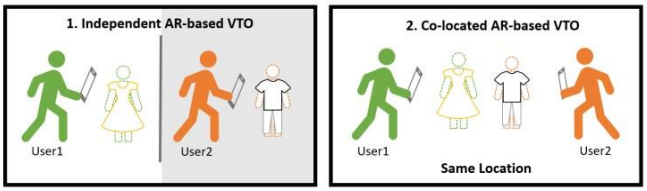

Figure 20. The experiment conditions

2) Evaluation design

Our study used a within-subject design in which two participants used the VTO system with two different modes of independent and co-located AR-based VTO in random order. The two conditions are as follows (Figure 20):

1. **Independent AR-based VTO.** Participants place their virtual avatar separately in their own physical environment and view their own personalized virtual body with garment models and posing or walking in the real world.
2. **Co-located AR-based VTO.** Participants can share their VTO experience with their partners at the same time and in the same place. They can communicate verbally and visually and give advice on each other's fitting effects.

We separated the participants into six pairs, where people of the same sex are in the same group. We asked each pair of participants to virtually try the clothes on and simulate the shopping experience using the independent AR-based try-on condition and the co-located AR-based try-on condition. Afterward, the participants were asked to complete a 7- Likert scale questionnaire to rate their shopping experience. At the end of the experiment, we interviewed the participants and gathered some open-ended feedback.

3) Results

We analyzed the result in terms of body similarity, enjoyment, usefulness, closeness, and user behavior. Paired t-test was performed using SPSS [45] to assess whether there were statistically significant differences between the means of the two conditions (Figure 21).

Body similarity. We analyzed the user body similarity through the statement, "I feel that the virtual body I saw was my own body." Although there is no significant difference found in body similarity ($p = 0.59$) between the two conditions, we found that their friends' evaluations of their virtual bodies often affected their perception of their own virtual avatar. Several participants mentioned that when they heard positive feedback from friends, for example, "This virtual avatar really looks like you," they felt that the virtual body became more similar to themselves. On the other hand, when participants heard negative comments from friends, they reduced the ratings of their virtual avatar.

Enjoyment. We analyzed user enjoyment through the statement, "This VTO system was enjoyable to use." We found that the participants rated the co-located AR condition ($p < 0.05$) significantly higher, meaning that it can provide users with a more enjoyable experience. The participants tended to spend more time and were more engaged in

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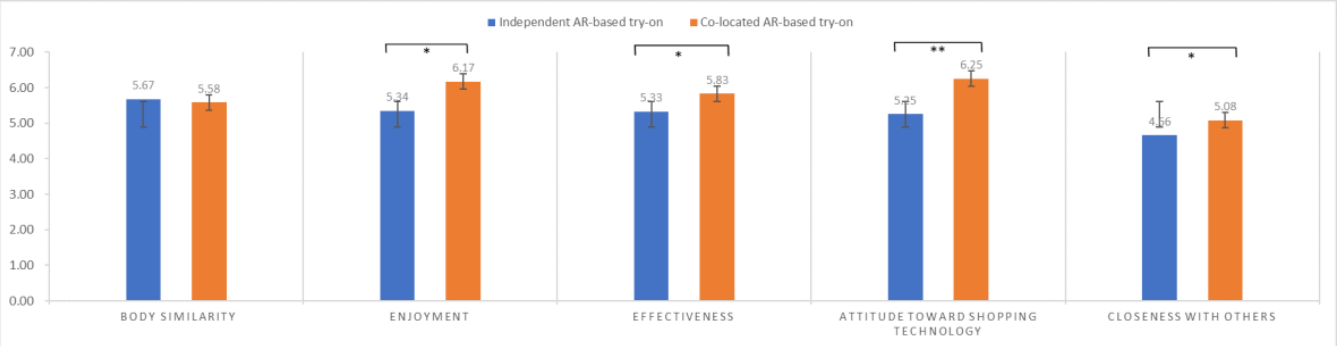

Figure 21. Perceived levels of body similarity, enjoyment, usefulness, confidence in fit problem, attitude toward shopping technology, and closeness. Note: *p < 0.05, **p < 0.01

shopping together with their partners in the co-located AR-based try-on condition. Compared with the independent VTO, they paid more attention to help friends choose clothes and give their personal opinions. P11 mentioned, "It's fun to try on clothes for my partner. I feel more engaged when we can talk to each other and try-on together; it is just like we are shopping together."

Effectiveness. We analyzed the system's effectiveness through the statement, "Using this VTO system would enhance my effectiveness in shopping." We found a significant effect on users' shopping effectiveness ($p < 0.05$). Most participants mentioned that using the co-located AR system allows them to receive recommendations from others. For example, P2 commented, "When I shared my VTO experience to my partner, I could get more helpful advice from my partner."

Several participants thought that comments from others can help them explore a completely new clothing style. P6 mentioned, "When I shop online alone, the styles of clothes that I choose are very similar to what I already have. When using this system, friends will often give me suggestions, encouraging me to try on new styles."

Many participants said that our system offers an intuitive try-on effect, which can help save time when shopping. For instance, P10 stated, "Friends can quickly help us eliminate clothes that are not suitable, which is a great way to save time on shopping."

Compared to just sharing links or outfit photos with friends, sharing an intuitive fitting experience with others can obtain a more accurate recommendation. P2 remarked, "When I shop online, I can only share links and images of clothes, and my friends can only give advice based on their imagination. It is not helpful for me."

User behavior. We analyzed the users' attitude toward our shopping technology through the statement, "I want to use this system when I buy some clothes online in the future." We found that the participants rated the co-located AR condition ($p < 0.01$) significantly higher than the independent AR condition. We also asked the participants' preferences for each condition at the end of the study. Consequently, 11 participants preferred the co-located AR-based try-on condition. Only one participant favored the AR-based independent try-on because he was worried that sharing his body with others would reveal his privacy.

Happiness and closeness with others. We analyzed the users' happiness when using the co-located AR system through the statement, "I feel happy when I am shopping with my partner." The participants strongly agreed that they feel happy ($M = 6.58$, $SD = 0.64$) when shopping with their partners. Most participants reported feeling happy and closer with their partners after using our system. P1 mentioned, "It allows me to experience the pleasure of shopping with friends." Furthermore, P12 noted, "Seeing our avatars doing real-life motions in the real world, similar to this kind of game-like try-on experience, makes me very happy."

We analyzed the closeness between participants by the inclusion of community in self-scale (IOS). The results showed that closeness with their partners increased from an average IOS score of 4.66 ($SD = 1.15$) to 5.08 ($SD = 1.24$) after the experiment ($p < 0.05$). Some participants thought that using our system can enhance their relationship and strengthen their social connections. P2 stated, "It's fun to try on clothes in the same space with my friend's avatars. We can talk to each other, see each other's avatars, and then interact with each other. I think our relationship has become closer."

We summarized the main results and presented explanatory analysis based on our observation during the study as well as findings from the interviews. The results indicated that Social Fitme can greatly improve the shopping pleasure of users and provide them a more engaging and effective shopping experience. Our system provides users an intuitive sharing VTO experience. Comments from others can not only help users make confident decisions, but also allows them to explore a completely new clothing style. Users can enhance their relationship and strengthen their social connection by using our system. We summarized the results in Table Ⅲ.

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TABLE III. SUMMARY OF RESULT

Theme	Conclusion
Effectiveness	**Helpful comments:** comments from others can help users make a more confident decision. **Diversified styles:**users can explore a completely new style based on advice given by others. **Intuitive sharing experience:** personalized avatars in AR provide a more intuitive way to share their outfits with others when online shopping, which can offer users a better judge of fit. **Filter mismatched selection:** users can eliminate the unsuitable selections quickly. **Detailed garment visualization:** users can view garments from multiple angles and in more details.
Happiness Closeness with others	**Enhance relationship:** using Social Fitme strengthen social connection and make users feel closer together. **Game-like shopping experience:** users feel happier when simulate try-on experience with others.
Enjoyment	**More engaged:** users are more enjoyable and engaged in sharing outfits with others, they tend to ask for other's recommendations and make a more confident choice.

VI CONCLUSION AND FUTURE WORK

In this paper, we presented a 3D VTO system to help consumers obtain a better sense of how they will look when purchasing clothes online. To allow users to assess how well the displayed products match their actual body, we personalized users' own virtual avatars corresponding to real users' human body shape and face features. Based on online garment images, we generated 3D virtual garments to personalize the human body. Users can fit their 3D user models with a selection of virtual garments, and view the animated body in the real-life scene, as well as various virtual scenes, to get a better sense of the dynamic effects of the clothes. An initial evaluation reveals that the VTO system is more enjoyable and convenient than that of using images only.

Augmented walking provides an interactive dynamic VTO experience for users, which gives them better understanding of the details of clothes. The virtual avatar wearing clothes in the real world can provide a better sense of "true fit," which helps users judge their fitting more effectively. Furthermore, most of the participants prefer using this system for online shopping in the future. They think that this system can increase their purchase confidence and solve the fit problem when shopping online.

However, our system still has certain limitations that can be improved. In the future, we plan to enhance our clothing animations and cloth simulation methods to provide users with a more realistic VTO effect. Motion capture can also be used to better simulate user's walking motion, to provide a more realistic and interactive fitting experience.

We also presented Social Fitme, a platform and concept for co-located social try-on system that supports personalized interactions through smartphones. The system implements interactive technology combined with AR and cloud technologies and provides users with a novel shopping experience. We conducted a user study to explore the effectiveness of our system and interactions designed to support the sharing of VTO experience in AR. We found some possibilities and advantages of multi-user online social shopping:

- **Try clothes on users' friends directly.** Rather than just imagine how the clothes look like on their friend's body, users can try clothes on the personalized avatar of their friend directly and view the effect on the dressed virtual body in the real-life scene quickly.
- **Explore a completely new style of clothing.** Our system allows users to experience the pleasure of physical shopping with friends, allowing them to choose clothes for each other, or even explore a completely new style of clothing that they would otherwise not try on by themselves.
- **More confident decisions.** The sharing VTO experience in AR can provide users with a more effective shopping experience. Sharing the intuitive dressed body allows users to obtain more accurate comments from others, thereby helping them make more confident purchase decisions.
- **Strengthen social connection.** The rating of IOS showed that the shared VTO system can strengthen social relationship between friends and make users feel closer to each other.

In the future, we will improve our work from these two perspectives:

1) **Improve sense of personalization with facial expression.**
Our personalization research result in VTO shows that the level of personalization can be improved to a certain extent, such that the realism and interactivity of VTO may be increased (e.g., facial expression of virtual avatar). Several participants mentioned that they hope that our system will add real facial expressions to make the virtual avatar more natural/humanlike and share the emotional attitude toward virtual clothes with others. Thus, future work may explore expression design of the personalized avatars to provide a more natural and interactive sharing VTO experience for users.

2) **Enrich social interactions with VTO.**
Our system allows users to share their virtual avatar with others from a social interaction perspective. We presented a new way for multiple users to experience a VTO experience in the local space. In the future, we hope to apply the shared AR-based try-on system to remote users, allowing multiple users to cross distance barriers and share fittings through natural communication.

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