Smart Fitting: An Augmented Reality mobile application for Virtual Try-On

Ohoud ALZAMZAMI*, Sumaiya ALI, Widad ALKIBSI, Ghaidaa KHAN,

Amal BABOUR, Hind BITAR

Faculty of Computing and Information Technology, King Abdulaziz University, Jeddah, Saudi Arabia

ualzamzami@kau.edu.sa, sali0105@stu.kau.edu.sa, walkibsi@stu.kau.edu.sa, gkhan0009@stu.kau.edu.sa, ababor@kau.edu.sa, hbitar@kau.edu.sa

***Corresponding author:** Ohoud ALZAMZAMI
ualzamzami@kau.edu.sa

Abstract: While online shopping has become popular in recent years, certain problems related to customer expectations about the appearance and fitting of clothing items still need to be solved. Online customers looking for clothing products may be unsatisfied as they do not have the possibility to try on clothes and view how they would look on them. Additionally, vendors are burdened with the cost of items returned by unsatisfied customers. Augmented Reality (AR) can help vendors to attract more customers and enhance their shopping experience. Customers are more likely to be satisfied with their purchases when they can try the clothes on before purchasing them, which ultimately reduces the return costs for vendors. This paper presents an AR mobile application called Smart Fitting which was developed in order to allow online customers to try on clothing items by using 3D models virtually. The most recent AR development tools for iOS operating systems, including XCode and Unity, are utilized for creating the proposed mobile application. After an integration testing for the mobile application functions, seven target female consumers participated in the usability evaluation for this mobile application which was meant to prove its ease of use and evaluate the customers' satisfaction. The obtained results showed that Smart Fitting can improve the users shopping experience by providing a more realistic clothes visualization than the traditional online shopping interfaces.

Keywords: Augmented Reality, Body Tracking, Unity, Superimposition, Virtual Try-on.

1. Introduction

Online shopping has become an everyday activity for many people around the world. A study has reported that 21% of shopping is performed in stores, while 43% is done online (Jaller & Pahwa, 2020). Online shopping is constantly growing, especially with the growth of e-commerce (Jaller & Pahwa, 2020), and its impact can be seen in many aspects of people's lives, such as extended business hours, lowering business operating costs, and broadening the scope of business to attract new customers (Maat & Konings, 2018). The fashion sector is a trending and among the fastest-growing areas of online shopping (Chakraborty & Biswas, 2020). Shopping for clothes online has become quite a trend and an essential activity in the busy schedule of people's lives (Rathnayaka, 2018). Several technologies have been developed and used in the fashion sector, allowing shoppers to search, think, and compare information anywhere and anytime (Bonetti & Perry, 2017). Examples of such technologies are mobile applications (Li et al., 2020), websites (Loureiro, Cavallero & Miranda, 2018), and 3D visualizations (Chakraborty & Biswas, 2020). However, there are some challenges for customers and vendors when using any of these technologies. Customers need to ensure that the clothes` appearance and fit suit their preferences. As a result, online retail stores deal with costly returns and re-shelving, which affects their profits. In recent years, augmented reality (AR) has gained much attention, and it has been used in designing the interfaces of applications in different domains, such as learning, healthcare, and e-commerce (Bekhit, 2022; Mahayuddin & Saif, 2021).

Incorporating AR into the fashion industry has been proposed to improve the customers' shopping experience (Caboni & Hagberg, 2019). AR is expected to revolutionize the shoppers' experience even in retail stores (Abou El-Seoud & Taj-Eddin, 2019; Meegahapola & Perera, 2017). This paper addresses the limitations of e-commerce, precisely the issue of customer's inability to test the appearance and fit of clothes while shopping online. It focuses on optimizing the user's experience by developing an application based on AR technology that helps them choose clothes based on visualizing

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how various types and sizes of clothes would look on them. Thus, it allows customers to make more informed purchase decisions based on trying on their desired clothing items.

Therefore, this paper focuses on using the latest AR application development tools, Unity and XCode, to develop a user-friendly mobile application called Smart Fitting that allows users to virtually try on clothes. The proposed application works by superimposing a digital model of the selected clothing item onto the view of the user's frontal plane of the body from a smartphone back camera. AR technology can be easily accessed by mobile devices such as smartphones; hence, the proposed application is developed using the iOS mobile application platform. The development process focuses on designing a user-friendly and easy-to-use application by following the waterfall methodology, which involves requirement analysis, software design, implementation, and testing. The solution is accessible to customers as they only need their smartphones to virtually try on some clothes. For example, to see a dress on the his/her body, the user will choose the specific cloth from a list of options. Next, the users will turn on the phone's rear view camera to view their frontal body through the phone screen. The user may hold the camera in front of a mirror or ask someone to take a picture of their front body. The application will detect the body boundaries and overlay the dress on the body so that users can visualize how it will look on them. In addition, users can choose from the available sizes for the selected clothing item and visualize the fit of the selected item and its size on their bodies using the live video captured by the smartphone back camera. Using the live video makes the trying-on experience more realistic for customers as they can move and change their poses while virtually trying on clothes. There are two main contributions of this paper. The first lies in developing a mobile application called Smart Fitting for virtually trying on clothing items on the iOS platform using Unity and XCode. The second consists in evaluating the application using integration testing for assessing the system's functions and usability to evaluate the ease of use for this application and the customers' satisfaction with it. The remainder of this paper discusses the development process for the Smart Fitting application. Section 2 presents an overview of recent studies on virtual try-on concepts and related applications. The data gathering, the establishment of requirements, and design process for the Smart Fitting application are discussed in Section 3. The required software and hardware tools are mentioned in Section 4 and 5, and Section 6 discusses the Smart Fitting application evaluation. The limitations of the proposed application and future work are presented in Section 7. Lastly, the conclusion is discussed in Section 8.

2. Related work

Augmented reality (AR) technology has helped to make great strides in the growth of store virtual try-on concepts (Meegahapola & Perera, 2017; Pachoulakis & Kapetanakis, 2012). The most common approach for virtual try-on has been based on virtual mirrors or fitting rooms where multiple cameras are set up to detect the user’s body and posture in order to augment a piece of cloth on the user’s body in real-time. Various systems use 3D cameras to acquire 3D images of users, which enable a better estimation of the body shape and measurements. KinectShop is an online virtual reality (VR) fitting room platform created by Razorfish. The platform is based on a Kinect camera and a big-screen TV. The platform allows users to virtually try on products by selecting them from the screen, where the Kinect sensor translates the user movements into on-screen movements, and the TV works as a virtual mirror (Pachoulakis & Kapetanakis, 2012). Bodymetrics developed a system in which a 3D avatar is generated for each user. The system enables users to scan their body size on a screen using Microsoft Kinect sensors and to see how the virtual clothes look on their avatars in different poses (Pachoulakis & Kapetanakis, 2012; Wang et al., 2012). Fitness developed a system that allows users to try on different virtual garments. The system enables users to scan their body measurements using Microsoft Kinect sensors, where the clothes are directly shown on their body on a screen instead of showing the clothes by using an avatar (Pachoulakis & Kapetanakis, 2012; Wang et al., 2012). Likewise, VIPodium uses the same technology to scan body measurements and allow users to view the clothes on their bodies at 360 degrees (Pachoulakis & Kapetanakis, 2012). The above discussed AR systems for virtual try-on apply only to retail stores. In these cases, the issue of users’ privacy has been brought up along with the fact that users are uncomfortable standing in front of cameras in fitting rooms (Sekhavat, 2016).

Existing alternative methods of virtual visualization include creating 2D/3D graphical models of clothes on top of virtual real-time images of the user (Holte, 2013). LazyLazy is a virtual dressing room-related system based on a web cam where the clothes' images are applied to a real-time snapshot of the user (Erra, Scanniello & Colonnese, 2018). Likewise, FaceCake is another virtual dressing room-related system where clothes are applied to a real-time user image. It allows the user to see how the clothes look from different angles (Holte, 2013). Another virtual room application is also presented in (Erra et al., 2018), where the clothes' images are applied to an avatar instead of the user's image, and the avatar is chosen as a close representation of the user's size and shape. Although this method gives a simulated impression of how the clothes might look on the user, it is often inaccurate, failing to consider the user's 3D body measurements (Holte, 2013).

On the other hand, some real-world applications use AR to detect and measure the body and superimpose a clothing item on the customer's body. MTailor application (MTailor, 2022) is an application for men and women that measures the user's body using a mobile device. It implements a 3D scan of the whole body and gets a digital measurement of all the body parts, including the arm, chest, and leg. Zeekit a company founded in 2013, has recently started using AR and image processing technology to allow its customers to virtually try on clothing items from an online catalogue using topographic mapping (Zeekit, 2022). Another recent application is the Gap's Dressing Room App, which uses 3D avatars and AR (Sayed, 2019). Other applications include in-store AR mirrors that are virtual fitting rooms produced by retailers like Uniqlo. The mirror displays clothes of different sizes that customers can choose from and virtually superimpose on their bodies (Sayed, 2019). This paper addresses the use of AR technology for virtual try-on of clothing items using personal mobile phones where users can view the selected items on real-time 3D models of their bodies when shopping online without worrying about privacy issues.

3. System design

In this section, the requirements for the Smart Fitting application are defined based on collecting relevant information from the target users.

3.1. Data gathering and the establishment of requirements

A quantitative online questionnaire was distributed to the target users to collect the required data for establishing the requirements of the proposed Smart Fitting application. The questionnaire is designed to assess the users' opinions about AR technology, the benefits of using this technology in online shopping for clothing, interface requirements, and the desired application features that can help provide a good user experience. The questionnaire questions and the percentages related to the users' answers are presented in Table 1. The questions were distributed randomly using different channels, such as email and social media, and the total number of participants included 200 women ranging in age from 15 to 50. The overall responses supported the development concept for the proposed application. In addition, valuable comments for determining the system requirements, including functional and non-functional requirements, were obtained from the participants.

Table 1. Questionnaire Questions and the Percentages Related to the Users` Answers

	Questions	Answers	Percentages
1	What is your age group?	15-19 years old 20-24 years old 25-34 35-44 45+	19.5% 58.5% 16.1% 3.9% 2.0%
2	Which method do you prefer the most while shopping?	Online Shopping Shopping at the stores	45.9% 54.1%
3	Have you ever tried an online virtual fitting room or in-store virtual fitting rooms or clothes?	Yes No	85.9% 14.1%
4	Does an AR clothing application for trying on clothes virtually raise your interest in trying on clothes in this manner?	Agree Disagree Neutral	71.7% 1% 27.3%

5	Would using an augmented reality application reduce your concerns about traditional online shopping (only images of clothes)?	Agree Disagree Neutral	65.9% 5.9% 28.3%
6	Would using an augmented reality application be enjoyable?	Agree Disagree Neutral	89.8% 0.5% 9.8%
7	Will using an augmented reality application help you make more informed shopping decisions?	Agree Disagree Neutral	76.1% 1% 22.9%
8	Will an augmented reality application help you save money when shopping online?	Agree Disagree Neutral	69.3% 7.8% 22.9%
9	Would using an augmented reality application reduce the time spent on browsing items?	Agree Disagree Neutral	57.1% 17.1% 25.9%
10	Would using an augmented reality application be more hygienic than trying on clothes in the store?	Agree Disagree Neutral	84.4% 3.4% 12.2%
11	Would using an augmented reality application improve your online shopping experience?	Agree Disagree Neutral	76.1% 1.5% 22.4%
12	Would you use the augmented reality feature regularly when shopping online?	Agree Disagree Neutral	62.4% 3.4% 34.1%
13	Will the augmented reality feature help you buy more suitable clothes for your fit?	Agree Disagree Neutral	80.5% 2.4% 17.1%
14	Which mobile application platform would you prefer?	iPhone Android	81.9% 19.0%
15	Do you prefer a 2-D or 3-D visualization of clothing items?	2-D 3-D	61.5% 38.5%
16	Would you prefer visualizing clothing items on customized avatars or your own body images/video?	Avatar My body images/video	23.4% 76.6%

The functional requirements derived from the gathered data are translated into use case models. The use cases for the authentication process are depicted in Figure 1. All registered users must log in with their usernames and passwords to access the application's features.

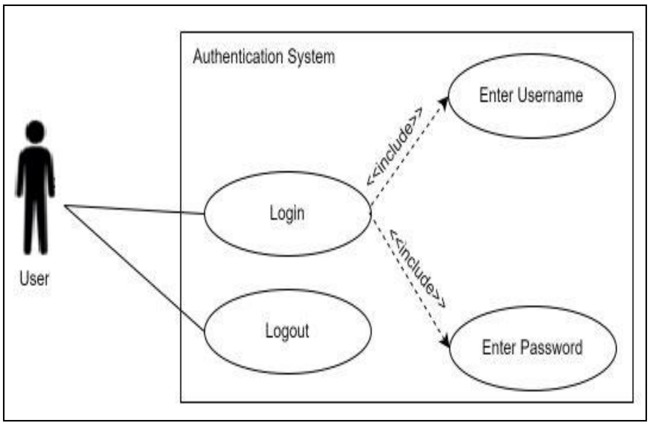


Figure 1. User authentication use case

Following authentication, the central system functions, which can be performed by either a shopper or an administrator user, are depicted as base use cases in Figure 2. Administrator users can update, add or delete clothing categories and item information, including clothing images. The different functions that shopper users can perform include creating an account, browsing and searching clothing categories, selecting a clothing item, trying on a clothing item, submitting a review, and viewing rating and feedback.

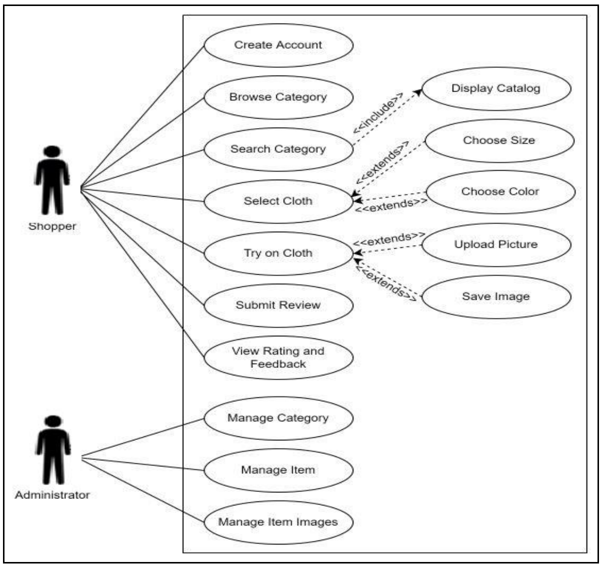


Figure 2. Smart Fitting System use case

Based on the gathered data, the non-functional requirements for the system are defined. Based on the participants' responses, Smart Fitting application is designed using the iPhone platform and supports the English language. It should be simple to learn and use without any assistance or manuals. The application should safeguard users' information and images by granting them password-protected accounts and not saving any images unless they save them. The background of the Smart Fitting application should be designed in light colors. User login credentials (username, password), user profile information (name, age), user email for verification, clothing item names, cloth types, sizes, and colors make up some of the data that the program must maintain.

4. Software and hardware requirements and tools

The leading software platforms used to develop the proposed application are Unity 2020.2.4f, Xcode 11, and Visual Studio 2019. The application is designed as a Unity3D project and installed into target devices using Xcode. These software platforms were chosen to create a user-friendly and intuitive iPhone mobile application. Unity 2020.2 .4f and Xcode 11 are used because these versions are compatible with AR packages (Bekhit, 2022; A non, 2022). Unity 2020.2 supports various AR features, such as body tracking and clothing item superimposition, which are required for the Smart Fitting application. An editor in Unity helps create multiple scenes, which hold specific objects called GameObjects. These objects are basic elements in Unity whose properties the developers can create and modify, such as 3D shapes, cubes, spheres, and other user interface elements. They can also be grouped in a hierarchy where applying an action to the parent object also leads to applying the same action to the child object. Unity provides a flexible user interface for developers to set different properties, such as materials and sounds. Platform-independent C# scripts control the application's flow and change the various components' behavior. Visual Studio is used for writing and editing back-end scripts in C# programming language.

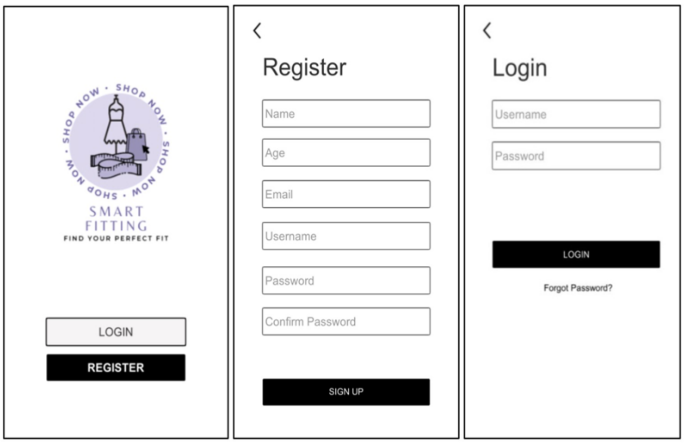
The hardware tools used for developing and testing this application are Mac computers to build the application and an iOS device to run and test the application. The AR packages and Xcode 11 require Mac operating system version Catalina. Hence, the MacBook computer used was compatible with MacOS Catalina. The mobile device used for testing the application is iOS 13. AR body tracking using the ARKit requires the A12 Bionic chip to be run on iOS13. This feature is only available for the iPhone XR/XS series. Hence, an iPhone XS device was used.

5. Smart fitting application development

In Unity, scenes are used for demarcating the various parts of a project by holding various objects. For an improved system management and an increased overall efficiency, the Smart Fitting program is implemented in two-component scenes, one scene holding the user interface screens and the second scene implementing the AR module of the application.

5.1. User interface

The interface prototype is designed with simplicity in mind, based on the requirements obtained from the data collection phase, to allow users to navigate through the screens and complete the required tasks without guidance or the need to follow a tutorial. The interfaces are created using Unity's User Interface (UI) elements. C# script coding is used for implementing all features and functions of the application. The back end of the interface was controlled by a single main script called UI manager. Figure 3 depicts the startup page, which includes login and registration options. PlayFab tool is a back-end service for Microsoft applications that saves the user's account and authentication information retrieved during the login process. It is used for authentication and security because of its flexibility and ease of integration with its dedicated game server. Users can also reset their passwords by selecting the "Forgot password" option.



a. Start-up screen b. Registration screen c. Login screen

Figure 3. Registration and login interfaces

The home screen is displayed once the user has logged in (see Figure 4). The home screen is intended to display all of the application's features and to provide an organized and easy-to-navigate application. The Try-on Cloth option takes users to a screen where they can select from the available clothing items and virtually try them on. Users can provide feedback and rate the application by clicking the Send Reviews button. The View Ratings option displays all user ratings, and the View Feedbacks option displays all user feedback. The logout button is also available on the home screen for logging users out.

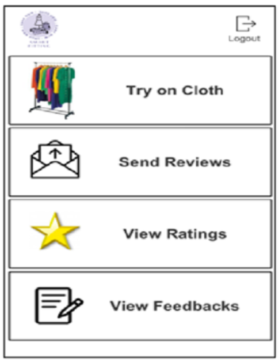
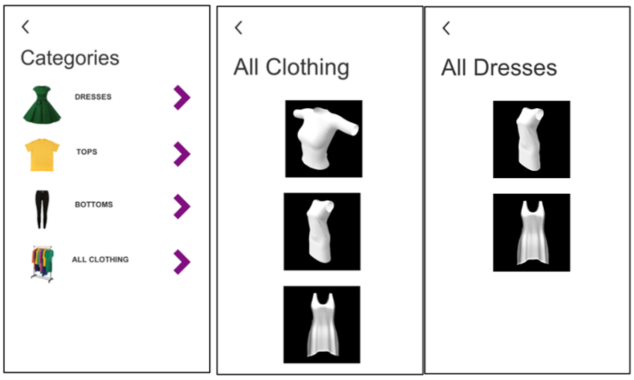


Figure 4. Home screen

Figure 5 depicts the clothing item browsing interfaces. The category screen displays the various clothing item categories. Users can search through each category by clicking on one category to see all the clothes in that category.



a. Category screen b. Screens for Clothing Items in a Specific Category

Figure 5. Clothing item browsing screens

Afterwards the user selects a category, and a clothing item from the chosen category. A screen that shows the selected item is presented along with the options to try on the selected item. The selected screen in Figure 6 shows the item's name as well as a clothing image of it with options for selecting available sizes and colors.

Figure 6. Example of item selection screen

The Playfab tool was used to create the feedback and rating screens. This feature enables the stakeholders to monitor the usefulness and the perceived quality of the application. As it is shown in Figure 7, the user enters the feedback as text and rates the usefulness of the application on a scale from 0 to 5.

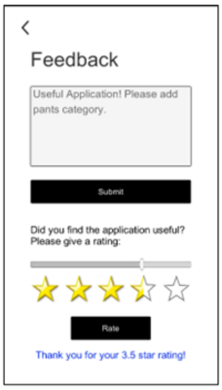
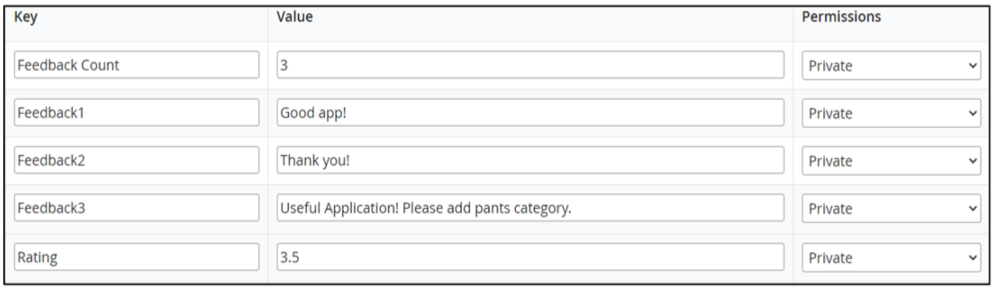


Figure 7. Feedback and rating screen

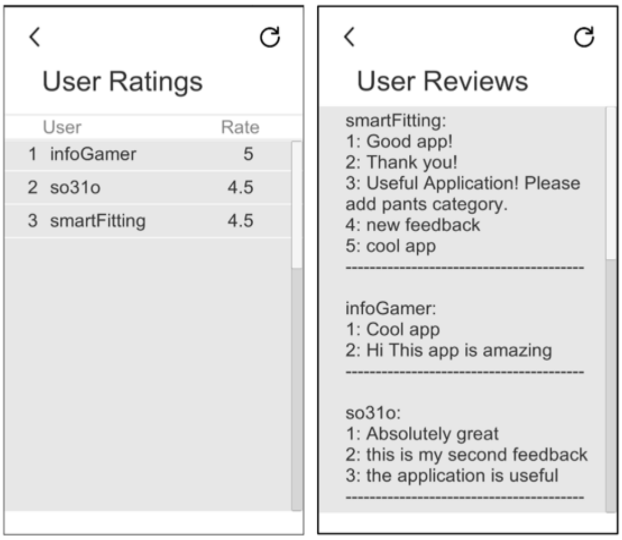
Users can submit their feedback about the application multiple times. At the registration stage, a feedback counter is set up to keep track of the number of feedback submissions made by each user, which is saved in the Playfab database (see Figure 8). Every time a user submits a feedback, this number of submitted feedbacks is incremented.



Key	Value	Permissions
Feedback Count	3	Private
Feedback1	Good app!	Private
Feedback2	Thank you!	Private
Feedback3	Useful Application! Please add pants category.	Private
Rating	3.5	Private

Figure 8. Feedback and rating information saved in the database

All users can view user ratings and reviews of the application from the home screen by selecting View ratings and View feedback options. Figure 9 depicts the screens for user ratings and feedback for three registered users. The screens are created in Playfab using the LeaderBoard and Player Statistics options, with a maximum of 100 users displayed on the screens.



a. View Users' Ratings screen b. View Users' Reviews

Figure 9. View user ratings and reviews screen

5.2. AR module

This section discusses the application's AR module in detail, beginning with the configuration of an AR scene in Unity and progressing to the 3D body tracking method and superimposition of clothing items.

5.2.1. AR scene configuration

Figure 10 shows the hierarchy of the main components added to the AR scene to facilitate the AR experience. With its default settings, an AR Session component is used to control the life cycle of the scene by enabling and disabling AR on the target device. An AR Session Origin component is added to perform the necessary transformations for converting and scaling the various tracked objects between local space (position of child objects relative to parent objects) and world space (each object's actual position in the entire scene). In addition, an AR Human Body Manager, a script that generates body tracking anchors and events, is used. The events are recorded with the help of the Human Body Tracking component, which includes two scripts: Human Body Tracker and Cloth Manager, to perform the final body tracking and clothing augmentation.

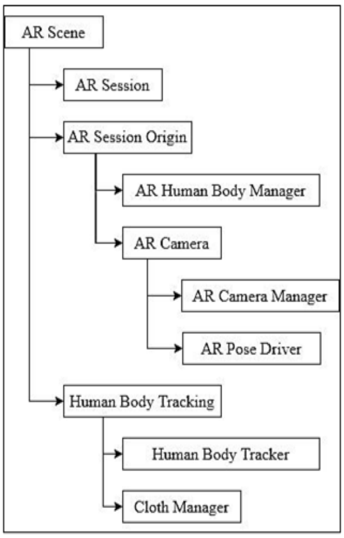


Figure 10. AR Scene configuration hierarchy

Additionally, an AR Camera component with an AR Camera Manager can activate AR features and control target device settings, including camera focus, illumination, and direction. Moreover, the AR Pose Driver analyzes the tracking data provided by the iPhone and modifies the clothing's orientation and position as it is necessary. The iPhone's back camera is used for this application, and the focus and direction settings are set to automatic mode.

5.2.2. Tracking the human body

In this application, the 3D body tracking technique is employed. A bone controller script defines 92 joints in the human body and generates a 3D robot-like skeleton connecting these joints. Because of the increased number of detected joints, this method produces better results with pose detection. Figure 11 depicts the outcome of 3D body tracking (a and b).

a b

Figure 11. Body Tracking using the 3D Tracking Method

This application uses the Human Body Tracker script to capture events from an AR Human Body Manager class instance and perform the appropriate actions. When a human body appears on the screen, the camera in the AR kit engine will detect the human body on the screen, and the AR Human Body Manager sends the events to the Human Body Tracker for proper action. The body tracker uses the skeleton generator script to generate the initial skeleton, and its pose is updated every time the human body moves based on the received tracking information until it leaves the tracking area. This cycle will continue until the AR session is completed. The three primary functions triggered by three types of events are depicted in Figure 12, which illustrates a rough outline of the 3D body tracking cycle.

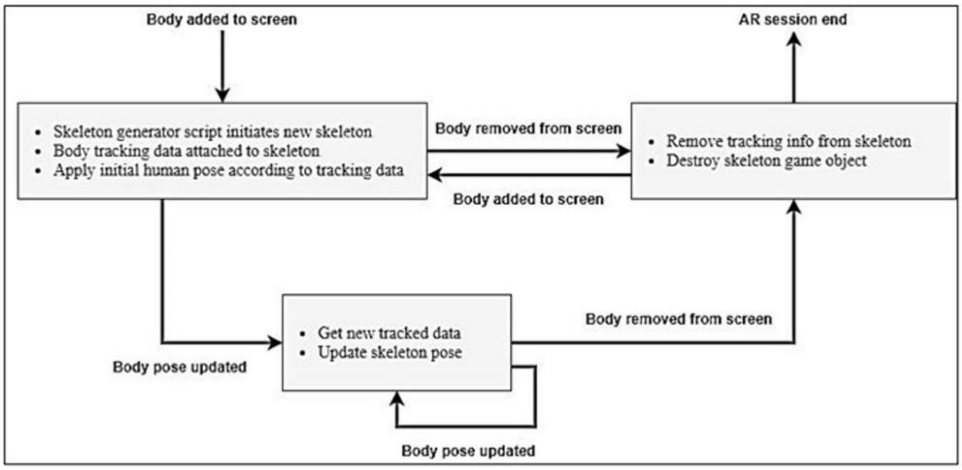


Figure 12. 3D human body tracking algorithm

5.2.3. Clothing Item Superimposition

Three 3D models of clothing items are collected and used since they are compatible with the 3D skeleton. 3D models of three clothing items of different types, namely dress, top and shirt, are imported. These items are saved as game objects in the Unity Asset folder, from which they were extracted via scripts. The asset folder stores files created outside Unity, converts them into a format that can be used in real-time applications and stores them in Unity's internal Asset Database. Thus, the 3D object can be rotated and scaled easily in the Unity space.

Superimposing the clothing item on the 3D skeleton model allows for clothing augmentation. The target body area is defined and named Chest using the skeleton, which comprises several joints such as the left and right shoulder, spine, and waist. The clothing item is attached to this area once it has been detected. The attachment of the clothing item to the 3D skeleton is shown in Figure 13. Finally, to visualize the augmented clothing item on the human body without the skeleton, the skeleton model was rendered invisible by changing the model's transparency property, as it is shown in Figure 13.

a. Including Skeleton b. Without Skeleton

Figure 13. Clothing item augmentation

The next stage is to allow the user to choose multiple clothing sizes and colors after having the clothing item imposed on the human body and the 3D skeleton. The multiple sizes and color options are implemented by modifying the fabric manager-script. This script contains all the methods for attaching the chosen piece of clothing to the skeleton and altering its shape and color according to the user's preferences. This script defines fixed measurements for small, medium, and large sizes. Figure 14 depicts an augmented shirt in three different sizes.

Figure 14. Clothing augmentation with different sizes

Each piece of apparel also comes in three color variants. Figure 15 shows three different clothing types in different colors.

Figure 15. Clothing augmentation with different colors and styles

6. Smart fitting evaluation

Two different testing methods are employed to evaluate the Smart Fitting mobile application: functional testing and usability testing. First, functional testing ensures that the system performs as expected and achieves its intended goal. Second, usability testing is performed on actual target users to ensure that the application requirements are met as effectively as possible. This aided in maintaining a minimum level of user expectations from the application and testing whether the application was usable without any tutorial or guidance.

6.1. Functional testing

For testing the system functionality, unit testing and integration testing are performed. After implementing each feature in the Smart Fitting application, unit testing is carried out as the first step for testing each function's behaviour. The white box testing is done after each module implementation to ensure that each part of the application works correctly. The results for each tested function were as expected, including registration, login, logout, forgot password, send feedback and rating, navigation, and AR module performance. The various components of the application are then combined to test the system's functionality and the connections between these components. Integration testing helps discover mistakes in the system and ensures that the system is operating as planned.

6.2. Usability testing

During usability testing, the developed user interfaces of the Smart Fitting application are evaluated in terms of learnability and ease of use. Data is gathered from seven different female users who were assigned to complete six tasks: (1) create a new account, (2) log out and log back in, (3) reset the password and log in with the new password, (4) try on any clothing item from among all clothing items, (5) try on a different size and color, and (6) send application feedback and rating.

An objective and subjective measure was used for each task to evaluate the application. As an objective measure, a timer is used to calculate the time it took each user to complete each of the tasks. Furthermore, the number of errors is tracked by calculating the number of incorrect clicks made by the user before completing the task. The results of the usability evaluation are shown in Table 2. The average recorded error for most tasks is 0, indicating the application was clear and easy to learn. Each assigned task took less than a minute to complete, and the overall testing time was about 2 minutes for all tasks.

Table 2. Usability Evaluation Results

	Task 1		Task 2		Task 3		Task 4		Task 5		Task 6	
User No.	Time	Errors	Time	Errors	Time	Errors	Time	Errors	Time	Errors	Time	Errors
1	20 s	0	12 s	0	35 s	0	15 s	0	20 s	1	7 s	0
2	30 s	0	10 s	0	32 s	0	14 s	0	19 s	1	10 s	0
3	21 s	0	15 s	0	40 s	0	17 s	0	21 s	2	12 s	0
4	24 s	0	12 s	0	37 s	0	15 s	0	21s	1	11 s	1
5	30 s	0	19 s	1	42 s	0	16 s	0	25 s	1	10 s	0
6	25 s	0	16 s	0	44 s	0	16 s	0	20 s	2	8 s	1
7	39 s	0	20 s	2	41 s	0	20 s	1	26 s	3	15 s	2
Average	27s	0	15s	0	39s	0	16s	0	22s	2	10s	0

The users' feelings and experiences are collected using a post-test questionnaire as a subjective measure. Nine questions were given to the users. The answers to each question were evaluated based on a Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). The questions are listed below:

- Q1: I was able to complete all the tasks.
- Q2: The application features/functions were easy to find.
- Q3: The application was easy to use and navigate.
- Q4: The language of the application was understandable and appropriate.
- Q5: I would not need the support of a technical person to use the Smart Fitting application.
- Q6: Most people would learn to use the Smart Fitting application quickly without guidance.
- Q7: The quality of the clothing item augmentation is enough to provide a realistic impression of the garment.
- Q8: Overall, I am satisfied with this application and will use it regularly.
- Q9: I will recommend the application to others.

Table 3 presents the results of the post-test questionnaire. It is concluded that all of the users were overall satisfied with the application. According to the results for questions 3-6, all participants agree that the application is easy to use and navigate. The language of the application is appropriate. In addition, the application is easy to understand and learn without any guidance or technical support. Only user no. 7 felt that she could not complete some tasks quickly and that some things in the application were not easy to find; however, the other users did not have this problem. Five out of seven users would recommend the application to others. They all agreed. Five out of the seven participants said that the clothes should look more realistic. All the participants agree that they will use the application regularly according to the results for question 8. The improvements suggested by the users include enhancing the realism of the 3D clothing items, increasing the number of the 3D clothing items, adding lower body clothes such as pants and skirts, and adding more sizes (XXS, XS, XL, and XXL). The results of the usability testing phase and user suggestions are considered for future work.

Table 3. Post-Test Questionnaire Results

User No.	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9
1	5	5	5	5	5	5	4	5	5
2	4	5	4	5	5	5	3	5	3
3	5	5	5	5	4	5	2	5	4
4	5	4	5	5	5	4	3	5	5
5	4	5	5	5	5	5	3	5	4
6	4	5	4	5	5	5	2	4	3
7	3	3	4	5	5	4	4	4	4
Average	4	5	5	5	5	5	3	5	4

7. Discussion, limitations, and future work

Several research studies have used AR technology in different contexts and with different aims. In comparison with other technologies used to improve the online shopping experience, such as Virtual reality (VR), AR can provide better 3D visualization of products because AR can overlay virtual clothing items onto one's view of the natural environment (Liu et al., 2020). This research enriches the literature on using the AR-Technology for virtual try-on. In 2019, Ahmad et al. (2019) applied AR technology on an Android mobile to transfer a T-shirt image from 2D to 3D. The user can scan the 2D T-shirt image from the paper printing catalog using a mobile camera and then view it successfully in 3D with different angles (Ahmad et al., 2019). Even though the authors used AR technology and a mobile camera to view the image in 3D, the aim of the research was different, and the domain and used technologies were limited in comparison with this research study. The Smart Fitting application allows the users to view the clothing items on the user body, in addition to rating the program and sending comments, which will improve the application's performance and add features based on users' comments.

In 2020, a personalized avatar with pre-defined and personalized movements was compared with a personalized no-motion avatar (Liu et al., 2020). The results have shown that personalized movements provide a better feel of the actual fit due to the high similarity between the user and avatar movements (Liu et al., 2020). However, the authors have found that virtual try-on with personalized movements has not generated a better attitude towards purchase intention and clothing products (Liu et al., 2020). This research tried to improve the user experience further on by using live images of the user instead of avatars with personalized movements. Also, the application in (Liu et al., 2020) was developed for the Android platform, while the Smart Fitting application was developed for the iOS platform. In 2021, a web application for virtual dressing rooms was built using the inFlask Web application and OpenCV, a Python Module. This web application allows users to try on some clothes in 2D. The developed web application successfully works with an Internet connection (Ahmad et al., 2019). As it was concluded by the authors, the web application saves users' time since users can try different clothes without visiting the store (Ahmad et al., 2019). This aligns with the results described in this paper, but the technology and application design were different.

One of the main limitations of this study is the evaluation of the developed application. The usability evaluation for the Smart Fitting application was carried out with only 7 users. As future work, the usability of the application will be evaluated for a larger number of representative users in order to obtain a higher degree of confidence with regard to the usability of the application, including its ease of use and learnability. Evaluating an application for a larger number of users as part of a focus group could help in enhancing the features of the application even further. In addition, a multidimensional model, such as the models proposed in (Iordache, 2015) and (Pribeanu, Balog & Iordache, 2017) could be used for evaluating the perceived quality of the proposed AR-based Smart Fitting application. Moreover, the usability testing for the developed application suggested adding new forms of clothing, such as pants, and improving the realism of the 3D clothing items, which will be considered in a future work.

8. Conclusion

This paper presents an iPhone mobile application that uses the iPhone's back camera to superimpose a digital model of clothing items onto the front view of a user's body. The program's key features include showing all accessible clothing categories, showing the colors and sizes for each piece of clothing, and enabling the user to try on clothing by using the iPhone's back camera virtually. Users can also send comments, rate the program, register and log in, and browse all user reviews, among other features. The app consists of two parts, one for the GUI using UI elements in Unity and the other for the AR module of the application configuring the AR scene. Smart Fitting employs a 3D human body tracking algorithm to determine the positions of the joints in the form of a skeleton after extracting the user tracking data from the live image on the back camera. 3D clothing models are placed and superimposed on the detected user's body according to size and color preferences by identifying the target body area on the skeleton. For each style of clothes, three colors and three fixed sizes (S, M, and L) are produced. Various components are combined and tested to ensure that the application operates as it was planned.

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* * *

Ohoud ALZAMZAMI is an Assistant Professor at the Department of Computer Science, Faculty of Computing and Information Technology, King Abdulaziz University. She received her Ph.D. degree in Computer Science from Florida Atlantic University in 2018. She is serving as a reviewer in several international journals in IEEE and in Elsevier, Wiley, and Springer. Her research interests include smart applications, and vehicular and wireless sensor networks.

* * *

Sumaiya ALI obtained her Bachelor's degree in Computer Science from the Faculty of Computing and Information Technology, King Abdulaziz University. She is currently working towards earning a Master's degree in Computer Science.

* * *

Widad ALKIBSI obtained her Bachelor's degree in Computer Science from the Faculty of Computing and Information Technology, King Abdulaziz University. She has experience in AI, software development, and management information systems. She is currently a project manager at the Tamer Group in Jeddah, Saudi Arabia.

* * *

Ghaidaa KHAN obtained her Bachelor's degree in Computer Science from the Faculty of Computing and Information Technology, King Abdulaziz University. She is currently a Senior project manager in the pharmaceutical ERP system and also the founder and CEO of Green Gaming for educating children about the environment through online games and events.

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Amal BABOUR received her Ph.D. degree in Computer Science from Kent State University, Kent, OH, USA, in 2017. She is currently an Associate Professor at the Information Systems Department, Faculty of Computing and Information Technology, King Abdulaziz University. She has participated as a Reviewer for multiple journals and conferences, such as JMIR, Applied Sciences, IEEE Access, ICISDM, and IHCI. Her research interests include artificial intelligence, machine learning, crowdsourcing, and information retrieval.

* * *

Hind BITAR is an Associate Professor at the IS Department, FCIT, King Abdulaziz University. Dr. Bitar received her Ph.D. in Information Systems and Technology, Health Informatics (Claremont Graduate University (CGU), USA, 2018). Dr. Bitar reviewed many scientific research papers for several journals and conferences, such as JMIR and JAMIA. Hind Bitar has made some scholarly contributions in the fields of health and energy informatics, as well as geoinformatics.