

VIRTUAL FITTING ROOM USING AUGMENTED REALITY

BY

LOH CHEAK LING

A REPORT

SUBMITTED TO

Universiti Tunku Abdul Rahman

in partial fulfillment of the requirements

for the degree of

BACHELOR OF COMPUTER SCIENCE (HONS)

Faculty of Information and Communication Technology

(Kampar Campus)

JAN 2020

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ABSTRACT

With the advanced technology growth, online shopping as known as e-shopping has grown exponentially throughout the world nowadays. Advances in e-shopping has driven a shopping revolution where customers are able to purchase items anywhere and anytime. Despite the benefits of e-shopping, the main drawback is the difficulty for online shoppers to try items on especially for clothing. Hence, a virtual fitting room using AR is proposed to be developed as a mobile application to allow shoppers to visualize how clothing looks and fits on their bodies without wearing it actually. This is to improve shoppers' shopping experience by giving them an ability to virtually try clothing on in order to check for size, fit or style. In this development, AR, human body detection and motion tracking are integrated to fit the model of garment to user's body in real-time by tracking user's body movements through the smartphone camera. The body skeleton-joint positions are recognized, detected and tracked using pose estimation model. In addition, the body and garment measurements are also analysed and interpreted to help in seamlessly fitting the virtual garments to the body.

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LIST OF ABBREVIATIONS

<i>AR</i>	Augmented Reality
<i>API</i>	Application Programming Interface
<i>GUI</i>	Graphical User Interface
<i>WSS</i>	Webcam Social Shopper
<i>CRM</i>	Customer Relationship Management
<i>RFID</i>	Radio-Frequency Identification.
<i>SDLC</i>	Software Development Life Cycle
<i>IDE</i>	Integrated Development Environment

Chapter 1 Introduction

1.1 Problem Statement and Motivation

With the advanced technology growth, online shopping as known as e-shopping has grown exponentially throughout the world nowadays. Advances in e-shopping has driven a shopping revolution where customers are able to purchase items anywhere and anytime.

Despite the benefits of e-shopping, there are some disadvantages which deter customers from purchasing items online. The most common problem faced by online customers is unable to try things on especially for clothing. Most of them wish to check whether the clothing fits in size as sometimes the purchased clothing does not match with the size description provided by the seller. Offering return policies or free shipping for returns is aim to compensate for inadequate fit and sizing content but it will bring much inconvenience to the seller.

Furthermore, some of the customers may prefer to shop in-store in order to try clothes on so that they can know whether the clothing fits them or not. However, for popular clothing store, the fitting rooms are usually full and there are long queues at peak hours especially holidays. Customers may need to queue up for a long time just to try few clothes on, thus lead to customer dissatisfaction.

In fact, customers will choose one or both of the clothing shopping styles which are online shopping and in-store shopping based on their specific demands. However, both of the ways are unable to achieve a goal which is allowing customers to check for size, fit or style of their favourite clothing without physically trying it on body. Therefore, an AR virtual fitting room is proposed in this project in order to help customers to accomplish their shopping goals.

1.2 Background Information

Augmented reality (AR) is a technology that delivers an enhanced view of real-world by superimposing computer-generated information such as graphics over the real objects and surroundings. The superimposed information can either add something to real-world as known as constructive AR or mask real-world as known as destructive AR. In AR-based environment, the virtual and physical information surrounding user's current location becomes interactive and digitally manipulated. Users are able to experience a new and enhanced version of natural world where the superimposed information provides assistance to users' daily activities.

Nowadays, AR applications have been applied to various types of industries such as entertainment, retail, education, medicine and etc. For example, Snapchat provides fancy filters for users to apply them over faces to take a picture using AR. The completed picture is then becoming the combination of real image with overlaid elements. Moreover, retail industry can benefit from AR technology by offering customers to try things on before placing any order at no cost of time or resources. One of the successfully cases is IKEA Place AR application which enables customers to preview and try out furniture items at home before buying it.

Other than that, in order to improve immersion of users into AR, human body detection is also integrated with AR technology to produce an application which allows users to interact and control the virtual element through body movements. According to *Figure 1.1*, Samsung Galaxy S10's AR Emoji is a AR mobile application that utilizes both human body recognition and AR technologies. The personalized 3D avatar model which is blended with the real-world environment moves like the user. This is done by capturing the specific points of the user's body and then tracking the body movements. In addition, with the help of human body scanning technology, accurate body measurements are able to be obtained for further analysis. The body measurements data can be utilized to helps users finding clothes that fit them perfectly.



Figure 1.1 – Samsung Galaxy S10's AR Emoji. (Tortozza, 2019)

In this project, a virtual fitting room using AR is proposed to be developed as a mobile application that supports commonly-used platforms such as Android. This AR virtual fitting room is equivalent to an in-store fitting area that is designated for customers to put on a piece of clothing before deciding whether to purchase it. It displays a user wearing a virtual garment on a smartphone screen by superimposing the model of the garment over the user's body in real-time. The superimposed garment model is fitted to the body according to the body and garment measurements by capturing the movements of the user through the smartphone camera. Since it enables customers to be virtually appeared like wearing clothing, AR, human body detection and motion tracking are the main technologies that are required to be integrated in the development. In addition, models of each garment is generated based on the size and appearance of the actual garment.

1.3 Project Objectives

The main objective of the proposed system is to enhance customer experience in clothing fitting by enabling customers to virtually try clothing on in order to check for size, fit or style. In this way, customers are able to shop and try their favourite clothing anywhere and anytime with smartphone. The main objective of the project is divided into sub-objectives as shown as below.

1. To detect and extract human body skeleton-based joint positions using smartphone camera.

The human body detection system is developed to detect the body parts included head, lower and upper body with minimum latency. The system should be able to inform the user about successful or unsuccessful human body detection by displaying the detected body skeleton-based joints or error message respectively. In addition, the time needed for detection and extraction should be shorter as compared to physically changing clothes or else this application does not make any contribution to time advantages for users.

2. To calculate body measurements based on the extracted body skeleton joint positions.

Body measurements are utilized to fit the virtual garments over human body in a more accurate way. The body measurements, including shoulder width, left and right arm length, left and right limb length are able to be obtained by calculating the distance between each of the body skeleton joint positions.

3. To fit virtual garments onto human body according to the extracted body skeleton joint positions, body measurements and garment measurements.

Models of virtual garments are generated based on the size and appearance of the actual garments. The virtual garments should have accurate sizing, fitting and styling rules similar to the actual garments. Furthermore, the collection of garments in detailed description should be also displayed and provided for selection so that users are able glance through the collections with simple action. By using augmented reality technology, the virtual garments are superimposed over the human body to create an illusion of “wearing clothing”. The body and garments measurements are also analysed and interpreted to help in seamlessly fitting the virtual garments to the body. The superimposed virtual garments movements will be detected and tracked to follow the real-time human body movements through camera.

4. To develop an interactive AR virtual fitting room mobile application on Android mobile platforms.

Each virtual garment is display in details so that users are able to view its styles and components in a more detailed way. Furthermore, the real-time scene will be displayed back in live video view through camera. Photo capture function will be provided for users to save the scene of wearing garment for future reference.

1.4 Proposed Approach/Study

This project consists of developing an AR virtual fitting room application using augmented reality and computer vision technologies for smartphones. Basically, the proposed application is built on Android mobile platform. Smartphone camera is the main requirement to detect, recognize and track human body movements in order to interact with the proposed application content such as virtual garment in real-time.

The Graphical User Interface (GUI) of the application is designed as simple and easy to use in order to make it applicable to people in all age groups. The garment catalogue, garment details and camera preview are the necessary and main user interfaces in this application. Therefore, the user interfaces have to designed and built based on the heuristic principles which are easy to learn, effective, easy to remember, error-free and pleasant to fulfil the usability criteria.

In addition, human body detection and motion tracking model is utilized to recognize and detect the human body skeleton joint positions in real-time. The live video is passed to the model to get classification result. The process is shown in *Figure 1.2*. The available garments are also translated into model in order to fit them to human body in real-time according to detected body skeleton-based joints, body measurements and garment measurements. In a nutshell, an AR virtual fitting room mobile application on Android mobile platforms is developed in integration with the human body detection and motion tracking model.

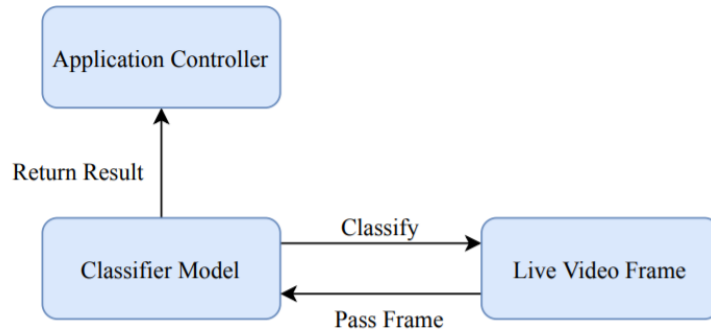


Figure 1.2 – Process of pose estimation.

1.5 Impact, Significance and Contribution

Compared to the early days, clothing shopping is getting easier and more convenient for customers and sellers especially through online shopping. However, the problem where it is compulsory to physically try clothing on body in order to check for size, fit or style is still cannot be solved. Therefore, one of the effective solutions to solve the problem is to develop an AR virtual fitting room.

From customer's point of view, it is very time-consuming and troublesome to repeatedly doing the same actions which are putting on and taking off clothes when changing clothes. With AR virtual fitting room, customers are able to virtually browse available collection of clothes, and even try their favourite clothing on to check for size, fit or style without having to pay a visit to a clothing store. Online customers will have improved confidence in size or style selection when purchasing clothing online while in-store customers will not have to spend time to queue up for fitting rooms in order to experience for size, fitting and style.

From clothing store's perspective, AR virtual fitting room may help them to fully utilize the available spaces of store and reduce cost on building fitting rooms. Usually, customers face challenges in contacting sales assistant once they are in fitting rooms. With AR virtual fitting room, it helps to enhance customer satisfaction by meeting the customer demand in a more convenient way, thus increase sales and improve image of the store. For

online clothing retailers, they encounter the difficulties in delivering accurate sizing solutions especially for those who sell multiple brands as there are different sizing rules for each clothing brand. With the help of AR virtual fitting room, their customers will gain more confidence when purchasing their garments and reduce the returns of garments due to inadequate size.

In a nutshell, clothing fit experience is something that should be paid with more attention for retailers to bring the ultimate in customer experience. Although there are size recommendation engines appeared in the market to tackle the problem, these technologies are still unable to achieve the goal which is simulating the sizing and fitting experience on body. Hence, AR virtual fitting room is going to make a tremendous contribution in online or in-store apparel industry with the effective way of enabling consumers to virtually try before buying.

1.6 Report Organization

The report is organized into 6 chapters and each chapter consists of its own contents while interrelating with each other. Firstly, the first chapter is concentrated on basic introduction of the project. Basically, this chapter aims to deliver a brief explanation of the project to enables readers to preview the important details that will be discussing about in the report later.

After the introductory chapter, Chapter 2 reviews the previous related existing systems that had been implemented with the similar solution. It consists of some literature reviews about the systems that are developed to allow users to check for fit, size or style without physically trying garments on the body. Each review will be compared and contrasted to analysis and interpret the pros and cons of the existing systems.

Then, Chapter 3 is mainly focused on the system design or overview which describes the flow of the proposed system. Each process included in the system is clearly stated and explained so that readers are able to understand easily. Furthermore, the

application features or the functional requirements are also described using use case diagram and use case description.

In addition, Chapter 4 presents about the methodology used, system implementation, user requirements, hardware or software used in development as well as the issues and challenges of the system implementation. The readers are allowed to obtain knowledge on how to implement or install the system in this chapter. In Chapter 5, verification and validation plans are designed to test the developed system in order to identify and locate the emergence of any potential errors or problems based on the results.

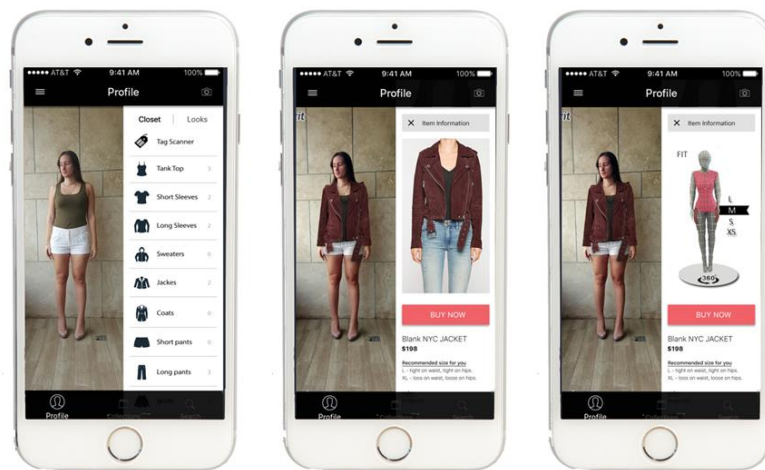
Lastly, a conclusion about the overall project is made in Chapter 6. The conclusion contains the review of the system, achievements and challenges encountered in this project. Future work is also discussed in this chapter to indicate improvements or further developments that can be made for this system in the future.

Chapter 2 Literature Review

2.1 Review on Existing Systems with Similar Solutions

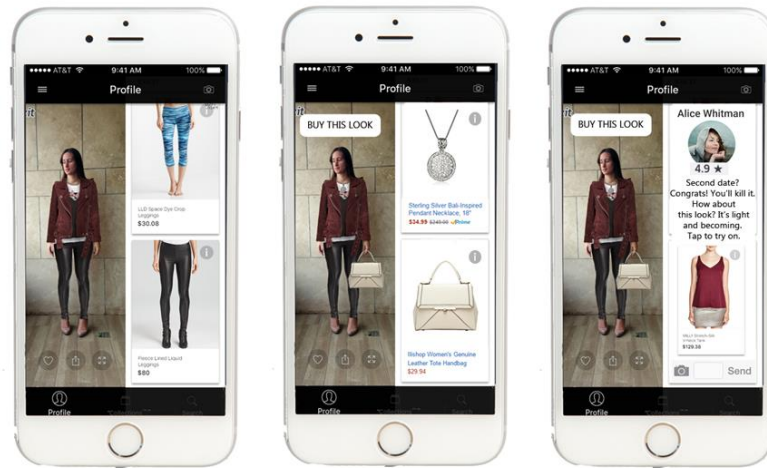
2.1.1 Virtual Fitting Room by Zeekit

Zeekit, a fashion tech start-up has developed the first virtual fitting room application which offers an interactive and different shopping experience for every person. It allows online shoppers to see themselves in any piece of garment found on-line without having to physically try it on by using their real photo and body measurements. Using real-time image processing technology, Zeekit map a person's image into thousands of segments by using its patented technology which involves rendering 3D maps over a 2D images. Besides, garment is also processed using the similar technology. Then, the processed person's image and garment are re-mapped into final simulation based on the equivalent points of them. The final simulation shows a person dressed virtually, taking into account few factors such as body measurements, size, fit and the fabric of the garment in accurate way.



Zeekit

*Figure 2.1 – A female shopper takes a full-body photography in tank top and shorts.
(Doupnik, 2016)*



Zeekit

Figure 2.2 – Sharing and purchasing function in the application. (Doupnik, 2016)

As shown in *Figure 2.1* and *Figure 2.2*, shoppers need to first upload a full-body picture of themselves in a tank top and fitted shorts or a little dress in order to make sure that their body shape is apparent. In this way, the application is able to analyse their bodies and turn 2D pictures into 3D data to create a realistic image of how garment looks on their bodies. The application then estimates their body measurements such as waist, bust, hip which the shoppers can adjust freely. After that, the shoppers tap any product they see online, in print or in store to instantly view how it looks and fits on their actual body by using the uploaded image of themselves. Each garment they try on can be mixed and matched from different retailers in their virtual closet, shared with friends or purchased through a link in the application.

In addition, retailers and brands can easily incorporate the Zeekit button into their online, mobile and physical stores to allow shoppers to virtually try on their entire catalogue of products. For instance, Zeekit cooperated with Rebecca Minkoff, a fashion company to new retail technology to the luxury market. Through this, Rebecca Minkoff's consumers are able to instantly access the feel of its products with immediacy through Zeekit application in order to try on products and purchase them.

2.1.2 Webcam Social Shopper

The Webcam Social Shopper (WSS) as known as Augmented Reality Dressing Room is a virtual dressing room software developed by Zugara which is software company in Los Angeles. In fact, online shopping offers optimization on searching, browsing, investigating and accomplishing a transaction but it did not help to engage experience like in-store experiences such as clothing fitting. (Takahashi, 2011) Therefore, WSS software was created to help online shoppers to gain confidence on making a purchase decision by seeing themselves “wearing” a garment through their webcam. As the software supports 2D, 3D and depth sensing cameras, Zugara has released two different type of version for different platforms which are an API for ecommerce platform integration and a Kinect enabled version which is called “WSS For Kiosks”.

The WSS software is an advanced product visualization tool that offers a way to help online shoppers to try clothing on virtually by turning camera into a real-time interactive mirror. It creates a visualization like wearing clothes by superimposing the static 2D image of virtual garments on top of human body. Furthermore, the software allows users to use hand motions to interact with the software content without having to return to keyboard or mouse in order to perform operation. By using this motion capture system, users are able to browse the various options of the garment by just moving arms above head.

According to Sterling (2012), users are able to try and run the software by accessing the website, www.webcamsocialshopper.com instead of installing any software or plugin to computer. As shown in *Figure 2.3*, user needs to grant permission for the WSS software to access camera and microphone. Through the camera, the software is able to detect the location where user is standing and adjust the position of the overlain garment on user's body appropriately. User is required to step 4 to 5 feet back from the camera and stand at centre of view so that the software can perform operations accurately and successfully. User is also allowed to browse, choose available options of the selected garment such as colour and size and take a photo of it by using hand motions. Kincaid (2009) claims that the clothes are basically just 2D images being pasted on top of body without any attention

being paid to body proportions. In addition, the software offers sharing outfit choices by integrating with Facebook and Twitter to allow users to send photos with the virtual garments for immediate feedback. *Figure 2.4* shows a sample result of a user wearing virtual garment.

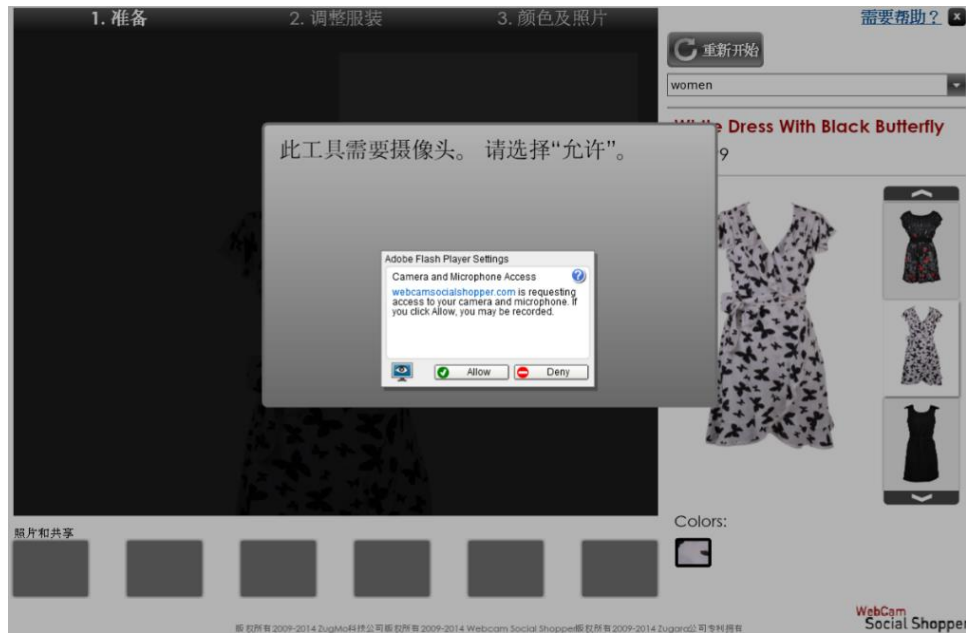


Figure 2.3 – WSS asks permission from user to access camera and microphone.

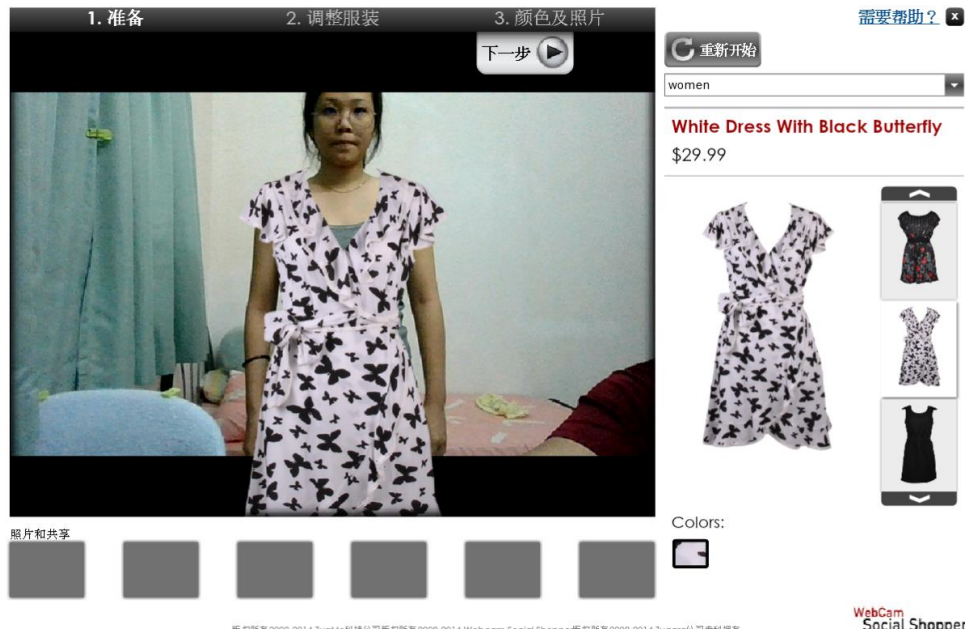


Figure 2.4 – A photo of a user wearing virtual garment on WSS.

Apart from that, WSS For Kiosks as shown in *Figure 2.5* is a Kinect enabled version of WSS software that provides fitting room solution for events and out of home advertising especially at mall. It performs the same function as how WSS For Web helps shoppers to virtually try clothes on their body. It also offers full integration with tablets for social sharing and Customer Relationship Management (CRM) data collection. Retailers could use these solutions to determine a shopper's fit, virtually show a shopper inventory virtually matched to their size, and even have a shopper buy directly from the kiosk station or site. Most garments that could be found on ecommerce site are also categorized and displayed in similar fashion on the kiosk station. (Szymczyk, 2019)



Figure 2.5 – A young shopper tries on virtual dress using WSS For Kiosks.

2.1.3 DressingRoom by Gap

The DressingRoom by Gap is a new pilot application created in collaboration with Avametric, San Francisco-based company and Google. It is a mobile application for only Google Tango smartphones which supports augmented reality computing. According to Alvarez (2017), the application enables shoppers to try on virtual garments on their personally selected avatar from five avatar body types according to their inputted information such as height and weight. If the shoppers like the garments, they can purchase the garments right there in the application.

As shown in *Figure 2.6*, a virtual 3D model of avatar body will be virtually displayed on the smartphone screen in real-time following the camera movements. It appears like standing in front of user through the smartphone camera. After chosen the favourite garment, the chosen virtual garments will be superimposed over the avatar body. In a way, the user can try on the garments to see what it is like wearing it at different occasions and timing. Users are also allowed to try on the garments in various sizes, colours and styles which are available now. In addition, users are able to place two virtual avatars wearing virtual garments side by side in order to make a comparison in a more effective way as shown in *Figure 2.7*.

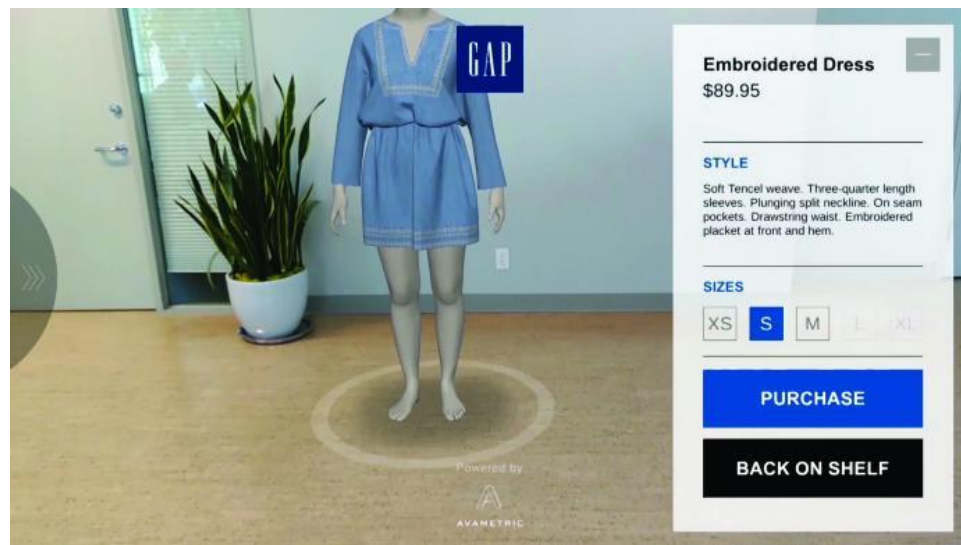


Figure 2.6 – A virtual avatar with virtual garment is virtually presented in the user's current environment using DressingRoom application.



Figure 2.7 – Two side by side virtual avatars with virtual garments in DressingRoom application.

In fact, in order to complete the development of the DressingRoom by Gap, Avametric technology, backed by the Google Tango augmented reality computing platform and ASUS hardware is utilized to obtain a lot of customer information. Gap has been working on the fit of their products to better match the way customers are shaped instead of just looking at “fit model” sizes. One of their top priorities is continuing to improve technical knowledge around how fabric stretch, drape and feel impact the sensation of fit. (Nunan, 2017)

2.2 Review On Virtual Mirror Technology

A virtual mirror or smart mirror is a device that works like a mirror by displaying a user's own image on a screen. Some versions of virtual mirror add AR technology to live video display while some of them create a virtual avatar of the user based on the user's body. Virtual mirror acts as a virtual fitting room system by combining Radio-frequency identification (RFID) and AR technologies. In this way, users are able to experience trying on virtual clothes on their body in real-time motion in a more interactive and effective way. Usually, most of the clothing stores are using this virtual mirror to display as an interactive mirror in their in-store fitting room.

According to Raturi (2018), the user is required to bring the garment to the front of virtual mirror which scans the garment. After getting the information of the scanned garment, top of the user's body will be superimposed with the garment image. Then, the reflected image in the virtual mirror will display a virtual appearance of the user with the garment. Most importantly, the garment follows the body movements with totally real virtual movements.

Furthermore, the lighting in the fitting room can be adjusted to enhance the user experience while trying out the garments. It can also display how the wearing garment looks at different times of day. Apart from that, the virtual mirror displays variety of options available for the garment for users to make a selection. Users are able to choose different size or colour option of the garment by using hand motions through the Microsoft's motion sensing camera, Kinect 3D. *Figure 2.8* shows a virtual mirror user tries on garments in-store.



Figure 2.8 – A woman tries on virtual garments using virtual mirror in-store.

2.3 Critical Remarks

Based on the existing systems reviewed, there are some strengths of the solutions used to solve the problem while there are also weaknesses and limitations of the solutions.

First and foremost, Zeekit's virtual fitting room is an application which allows users to instantly view how the selected garment looks and fits on their body in image. Based on the uploaded full-body picture of user, the application analyses user's body measurements such as waist, bust, hips which user can adjust them freely to provide more accurate measurements. As the application also turns a 2D image into 3D data, it is able to adjust the virtual garment to fit to user's bodies based on the body measurements. Furthermore, retailers and brands are allowed to incorporate the Zeekit button in their online, mobile and physical stores so that their shoppers could enjoy the try-on function. In addition, users are able to share with friends or purchase from different retailers through a special link in the application.

On the other hand, the main weakness of the application is that the try-on function is in static mode. The final simulation of virtual garment and human body is in static image which could not be view in different angles. Users are unable to feel the realism as they only can view how the virtual garment looks on the front body. In this case, users might not be interested in the try-on function as it does not help users much in deciding whether to purchase it or not. *Table 2.1* shows the summary of strengths and weaknesses of Zeekit's virtual fitting room application.

Table 2.1 – Strengths and weaknesses of Zeekit's virtual fitting room application.

Strengths	Weaknesses/Limitations
<ul style="list-style-type: none"> • The virtual garment is adjusted fitting to human body accordingly. • Incorporation function is provided for retailers or brands' online, mobile and physical store. • Sharing and purchasing function is provided for users. 	<ul style="list-style-type: none"> • Static image.

Besides, Webcam Social Shopper (WSS) is a virtual fitting room using augmented reality by overlaying image of garment over the human body in real-time. Compared to 3D modelling, the cost of creating and generating a 2D image of a garment is low. As a 2D

image is lighter than a 3D model, it does not cost much to integrate the 2D image with the software. By using motion capture system, users are able to browse and control the colour, size options of the chosen garment without returning to keyboard or mouse to interact with the software. This motion capture system also helps users to capture a photo of themselves wearing virtual garments. In addition, the sharing option offered by the software is one of the real strengths which allows users to obtain immediate feedback about the outfit from their friends on social media.

On the contrary, the overlaid virtual garment is not fitted seamlessly to human body according to body and garment measurements. The virtual garment will be running from its appropriate position due to human body movements in real-time. In order to solve this problem, the developers release a solution by allowing users to enter their body measurements to get a fitted image. As the virtual garment is static, users are required to regularly face the camera with front body or else the virtual garment will not be overlain on the body appropriately. In addition, one of the limitations of WSS software is the low accuracy in human body detection due to the environment changes especially when it is low in brightness. *Table 2.2* shows the summary of strengths and weaknesses of WSS software.

Table 2.2 – Strengths and weaknesses of WSS software.

Strengths	Weaknesses/Limitations
<ul style="list-style-type: none"> • Low cost of generating 2D image of garment. • Motion capture system to obtain user input without keyboard or mouse. • Sharing option for users to exchange feedback on social media such as Facebook and Twitter. 	<ul style="list-style-type: none"> • The virtual garment is not adjusted fitting to human body accordingly. • Static virtual garment. • Low accuracy in human body detection due to environmental condition.

Apart from that, DressingRoom by Gap is a virtual fitting room mobile application by generating a virtual avatar based on user inputted information such as height and weight

and allowing users to try the favourite garments on the virtual avatar. In this application, the virtual avatar and garment are displayed in 360-degree view. As smartphone is lightweight and portable, users are able to see how the garment looks on the virtual avatar body from different angles in real-time through the smartphone camera. In this way, it creates an idea for users to imagine like wearing the garments on their body in their current environment. Furthermore, the improved technical skill around how fabric stretch, drape and feel impact the sensation of fit from the application will enhance the realism. It helps to enable users to look and feel how the garment will actually fit on their body.

On the other hand, the main weakness of this application is the real difference between virtual avatar and physical human body. Virtual avatar is unable to fully represent the human body due to the reason that each body part has different size and colour of skin. This may cause users to purchase garments with inadequate size, thus lead to customer dissatisfaction. In order to solve this problem, users need to key in all the measurements of each body part to create a perfect virtual avatar but it is quite time-consuming and troublesome to do so. *Table 2.3* shows the summary of strengths and weaknesses of DressingRoom application.

Table 2.3 - Strengths and weaknesses of DressingRoom by Gap.

Strengths	Weaknesses/Limitations
<ul style="list-style-type: none"> • Able to see how the garment looks on the virtual avatar from different angles in real-time. • Able to let users look and feel how the garment will actually fit. 	<ul style="list-style-type: none"> • Difference between virtual avatar and physical human body.

Besides, there are some advantages and disadvantages of the virtual mirror technology reviewed. One of the advantages of this technology is the ability of virtual garment to be fitted seamlessly on human body. The virtual garment follows the body movements with totally real virtual movements in real-time to create a visualization like the user is wearing it, thus enhance customer experience. Furthermore, users do not have to touch on the virtual mirror to perform operations such as choosing garment option. By

using motion capture system, they can easily change garments with a swipe action of hand. In addition, users are able to view how the virtual garments looks on their body at different times of day by using virtual mirror. This can help to enhance immersion of users in the virtual environment.

On the contrary, the cost of building a virtual mirror is high due to the expensive depth sensors such as Kinect 3D. In addition, it also needs to be installed on a device with high performance speed as it consumes heavy processing power. It is also limited to in-store shoppers as the virtual mirror is large in size. In this case, online shoppers do not have chance to experience clothing fitting online. Users have to pay a visit to the store if they want to try garments on using virtual mirror. *Table 2.4* shows the summary of strengths and weaknesses of virtual mirror technology.

Table 2.4 - Strengths and weaknesses of virtual mirror technology.

Strengths	Weaknesses/Limitations
<ul style="list-style-type: none"> • The virtual garment is adjusted fitting to human body accordingly. • Motion capture system to obtain user input without touching the virtual mirror. • Enables users to view how the virtual garments looks on their body at different occasions and timing. 	<ul style="list-style-type: none"> • Expensive cost to build a virtual mirror. • Limited to in-store shoppers.

Chapter 3 System Design

3.1 System Overview

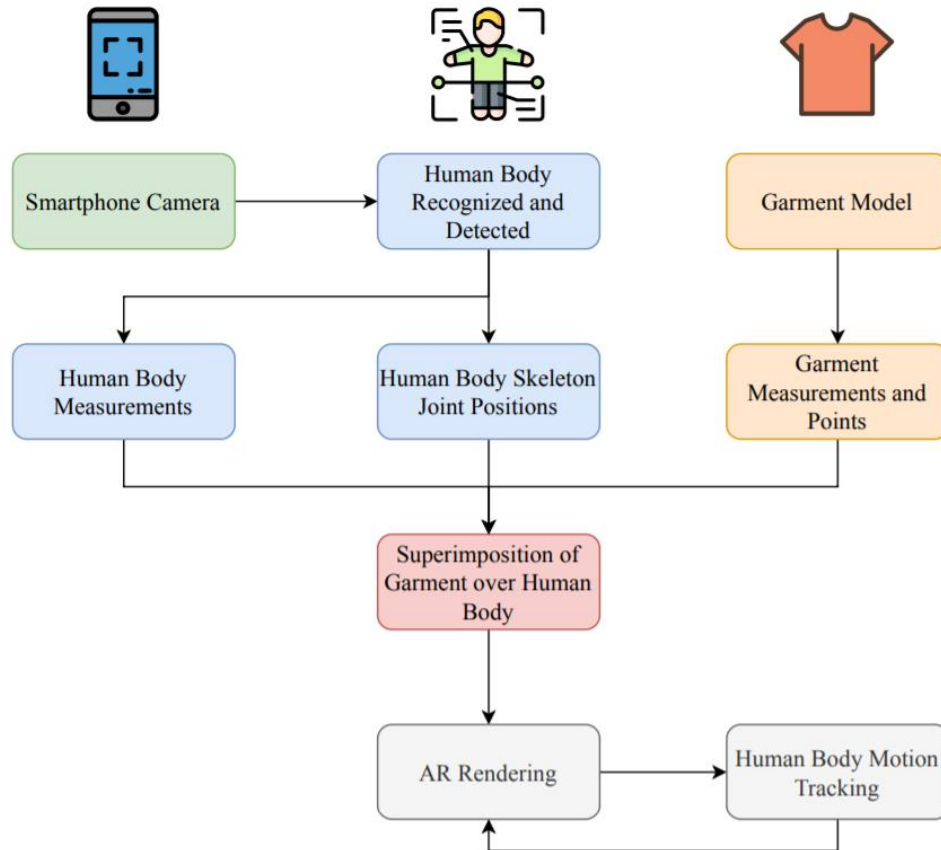


Figure 3.1 – Flow diagram of system overview.

As shown in *Figure 3.1*, the smartphone camera is used to detect and scan the user's body in order to obtain body skeleton joint position information and body measurements of the user. Then, the virtual garment is superimposed over the user's body by computing the data of body measurements, body skeleton joint position and garment measurements. In this way, the virtual garment can be fitted seamlessly to the user's body for enhanced realism. Through the smartphone camera, the virtual garment follows the tracked user's body movements with real virtual movements in order to ensure that the virtual garment is fitted to the user's body. The virtual garment will be kept rendering in the real-world view according to the body movements.

3.1.1 Customized Camera

In order to create and embed a customized camera in the application, android.hardware.camera2 package from Android, as known as Camera2 API is integrated and implemented to provide an interface to individual camera devices such as front and back camera which are connected to an Android device. Since it only supports Android API 21 and above, the minimum SDK version of the application is set to 21. In addition, the camera permission is declared in Android's manifest file to allow use of camera hardware and other related features.

By using this package, a camera device is modeled as a pipeline as shown in *Figure 3.2*. It takes in requests for capturing a single frame as an input and capture single image based on each request. The requests are processed in-order and multiple requests are allowed to run asynchronously to maintain full framerate on Android device in order to reduce latency.

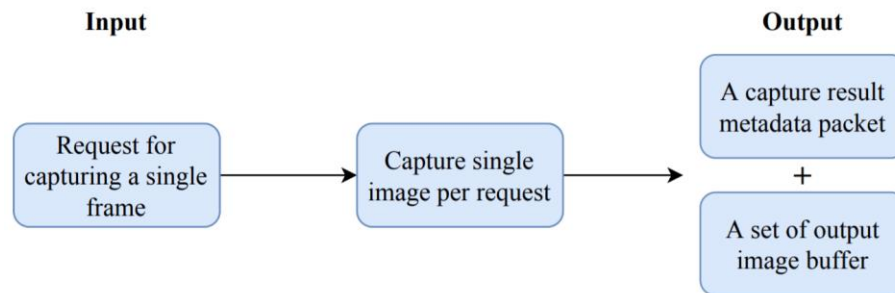


Figure 3.2 – Camera device's model pipeline stage.

The features of camera hardware such as autofocus and switching facing are included in this application to allow user to capture body skeleton joint points by manipulating the camera in a more convenient way. In order to have successful recognition and detection, user is required to stand 4-5 steps way from the device and include the body fully in the camera. The system may not be able to obtain the accurate body skeleton joint positions if only partial body parts are exposed.

3.1.2 Human Body Recognition, Detection and Motion Tracking

In order to recognize, detect and track human body, pose estimation model for mobile by TensorFlow Lite is implemented to estimate the pose of a person in live video by estimating where body skeleton joint positions are. The joint positions detected which are indexed by "Part ID" has confidence score from 0.0 to 1.0. There are 14 joint positions detected including top, neck, right shoulder, right elbow, right wrist, left shoulder, left elbow, left wrist, right hip, right knee, right ankle, left hip, left knee, left ankle, as shown in *Figure 3.3*. In order to implement it, the model file is imported into the application as an asset.

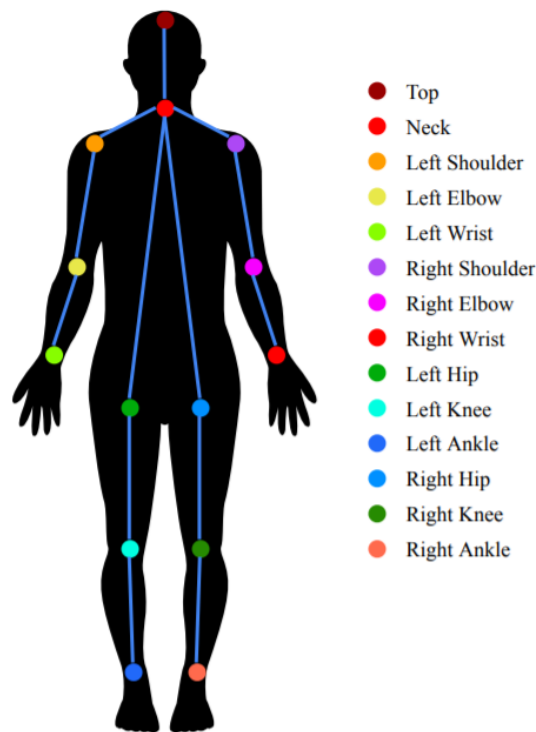


Figure 3.3 – Body skeleton joint positions.

Furthermore, OpenCV library is downloaded and imported into the application as a module. Its native libraries are also imported into jniLibs folder to be integrated with the application. Some of the functions from OpenCV are used to read the frame and feed the image data into the model classifier to carry out pose estimation.

Once the model and OpenCV libraries are loaded successfully, the image data is processed by Gaussian Blur to get enhanced image in order to increase classification accuracy. On the other hand, a set of heat maps is produced and generated to simultaneously capture features at a variety of scales. The heat maps predict the probability of the skeleton joints occurring at each pixel of the image. When the joint positions are successfully detected, the results will be returned back from the classifier. For real-time view, the live video is passed to the model in frame by frame and then, the model returns the classification result back to the application.

3.1.3 Generation of Garment Model

In this project, garment model has to be customized to match with the skeleton joint positions since there's no apparel dataset which is suitable to be implemented. The garment model is generated based on actual garment with transparent background to provide accurate size and style to user in order to enhance the virtual clothing fitting experience.

Furthermore, the garment model is saved as Portable Network Graphics (PNG), a type of graphics file-format that supports lossless data compression. The reason to choose PNG format is because the data is preserved and there is no loss in data every time it is opened or saved. The most main advantage of PNG is it supports transparency compared to other graphics file-format such as Joint Photographic Experts Group (JPEG). In addition, Firebase Real-time Database is also utilized to store garment data including title, category, description and options of colours.

3.1.4 Superimposition of Garment Model over Human Body

Once the body skeleton joint positions are successfully detected, the virtual garment will be superimposed over the body based on the data of body measurements, body skeleton joint position and garment measurements. In order to do superimposition, garment model is converted into Bitmap class which is from android.graphics.Bitmap package. Bitmap is used to create realistic graphic and image. Bitmap is a two dimensional matrix composed

of rectangular mesh of cells called pixels, each pixel containing a colour value as shown in *Figure 3.4*. They are characterised by two fundamental parameters which are the number of pixels and the information content as known as colour depth per pixel. Each pixel of the Bitmap will be handled and processed in custom way to match with the body skeleton joint points.

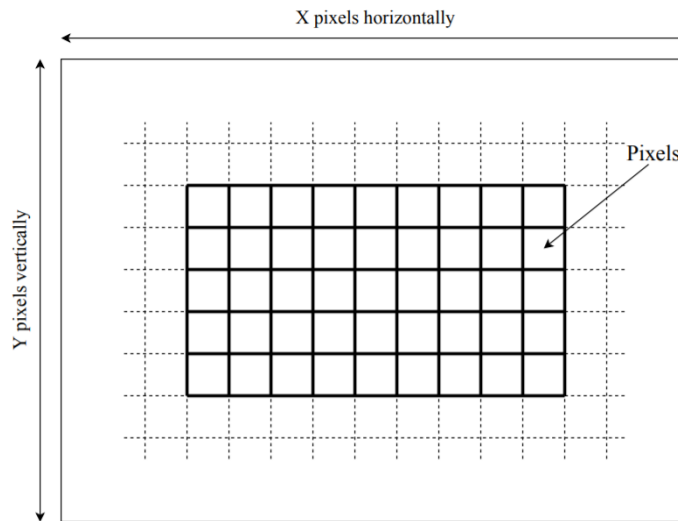


Figure 3.4 – Pixel description of Bitmap.

Furthermore, `android.graphics.Matrix` package from Android is integrated to perform scaling and transformation of the garment model to generate a matrix. The scaling of garment model is implemented based on the body measurements. The measurements are calculated based on the distances between each of the body skeleton joint positions as shown in *Figure 3.5*. The body measurements include shoulder width, left and right arm length, left and right limb length.

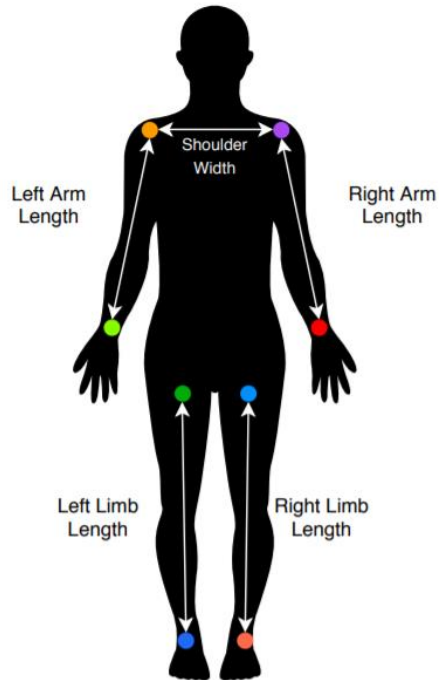


Figure 3.5 – Body measurements based on skeleton joint positions.

On the other hand, the garment model is transformed frame by frame according to the body movement tracked in real-time. The offsets for transformation will be set according to the body skeleton join points. In addition, android.graphics.Canvas package is utilized to draw the garment model onto the live video view based on the matrix generated with scaling and transformation parameters.

3.2 System Architecture Design

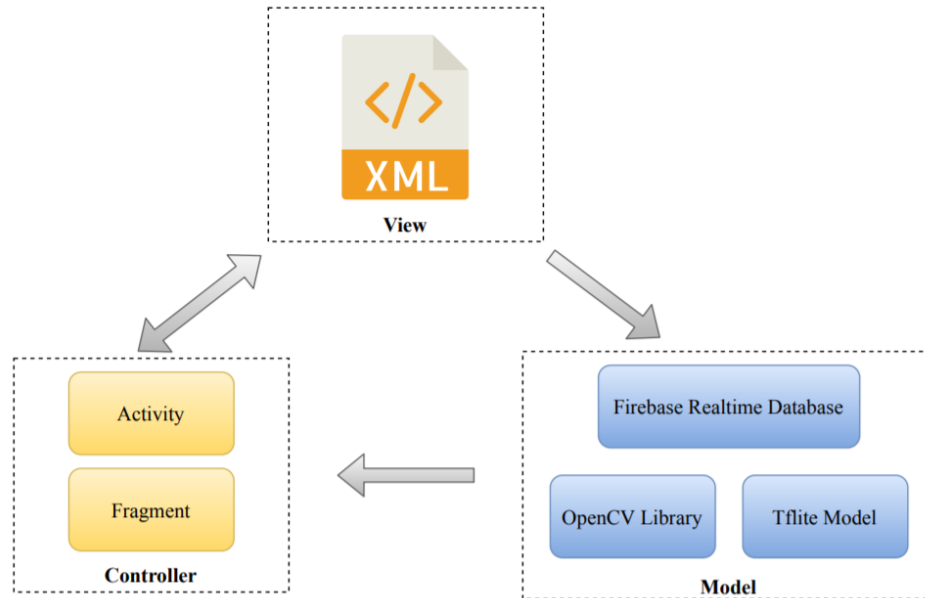


Figure 3.6 – MVC architecture pattern.

In this project, the application is designed based on Model-View-Controller (MVC) architecture pattern as shown in *Figure 3.6*. MVC is a solid, established pattern that aims to isolate and separate the different aspects of an application into presentation and interaction. Each layer is responsible for an aspect of the app. According to MVC architecture pattern, there are 3 logical components that interact with each other which are Model, View and Controller.

The Model component is the data layer, responsible for managing the application logic and data as well as handling associated operation on that data. Examples in this project are Firebase real-time database, OpenCV library and Tensorflow Lite model. View is the UI layer which defines and manages how the data from the Model is presented to the user data. Controller is the logic layer, responsible for managing of the user's behaviour and interaction such as item click event and updating the Model if needed. In this approach, every Activity and Fragment class in the application will act as Controller layer such as click listeners and item click listeners and etc.

3.3 Application Features

This section details the functional requirements of each features of the application.

The following table (*Table 3.1*) contains the list of main features to be implemented in AR Virtual Fitting Room mobile application in this project. *Figure 3.7* shows the overall use case of the application.

Table 3.1 – Application features.

Feature ID	Feature	Description
F001	Browse Garment Catalogue	To allow user to browse available garment catalogue.
F002	View Garment	To allow user to view garment's details.
F003	Capture Body Skeleton Joints	To allow user to capture body skeleton joints in real-time.
F004	Try Garment On	To allow user to virtually try garment on in real-time.
F005	Snap Photo	To allow user to snap a photo using smartphone camera.

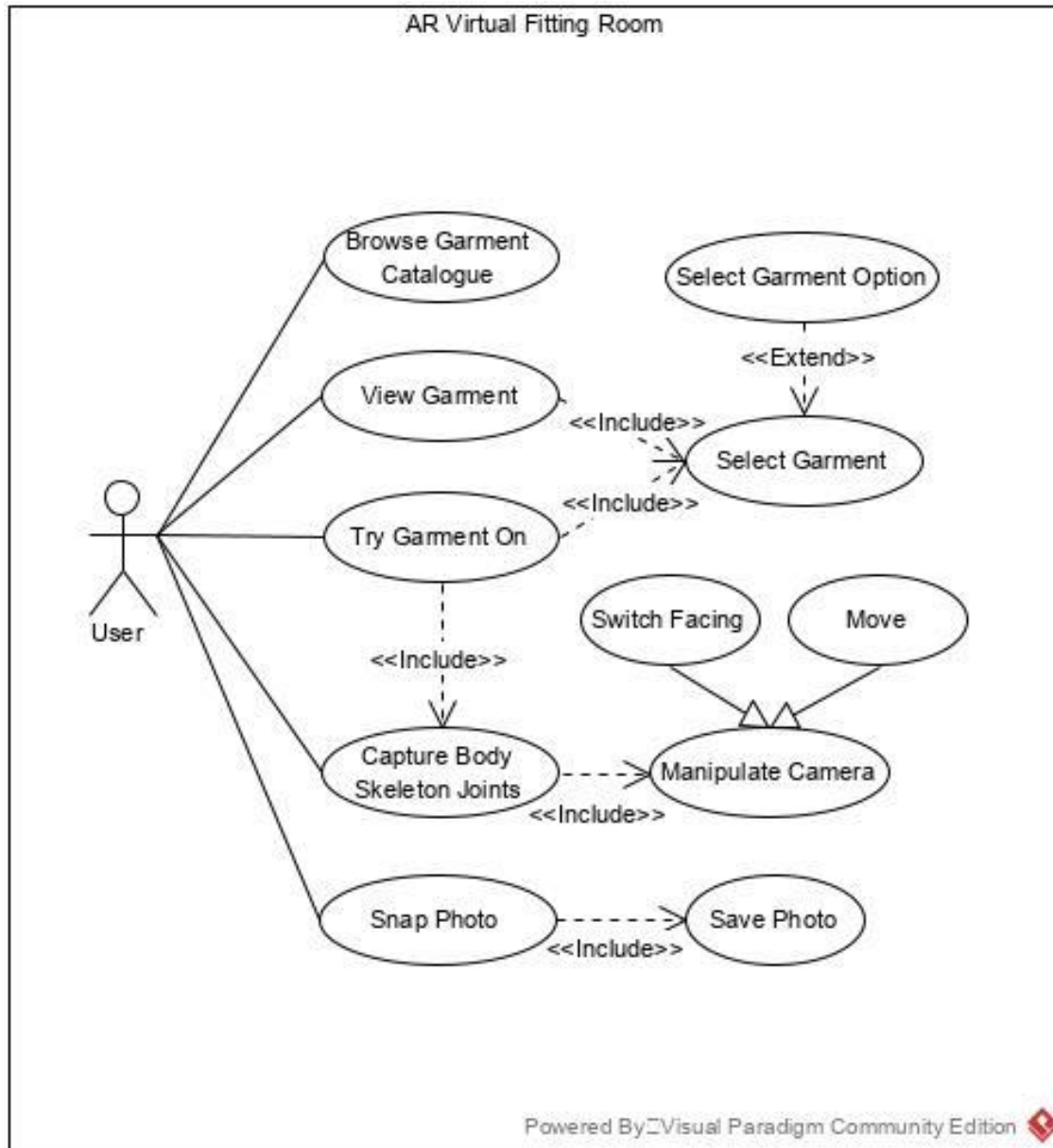


Figure 3.7 – Use case diagram of the proposed system.

3.2.1 F001 Browse Garment Catalogue

The following table (*Table 3.2*) shows the details of this feature as known as use case description, followed by an activity diagram (*Figure 3.8*) to illustrate the activity flow of the feature.

Table 3.2 – Use case description for F001 Browse Garment Catalogue.

Use Case ID	UC001	
Feature	F001 Browse Garment Catalogue	
Purpose	To allow user to browse garment catalogue.	
Actor	User	
Trigger	User navigates to garment catalogue.	
Precondition	The application is in “Running” state.	
Scenario Name	Step	Action
Main Flow	1	User navigates to garment catalogue.
	2	User chooses garment category.
	3	System displays the available garments based on the selected category in the catalogue.
Alternate Flow – No Garments in the Selected Category	2.1.1	User chooses a category which does not have available garments.
	2.1.2	System displays “No Product Found”.

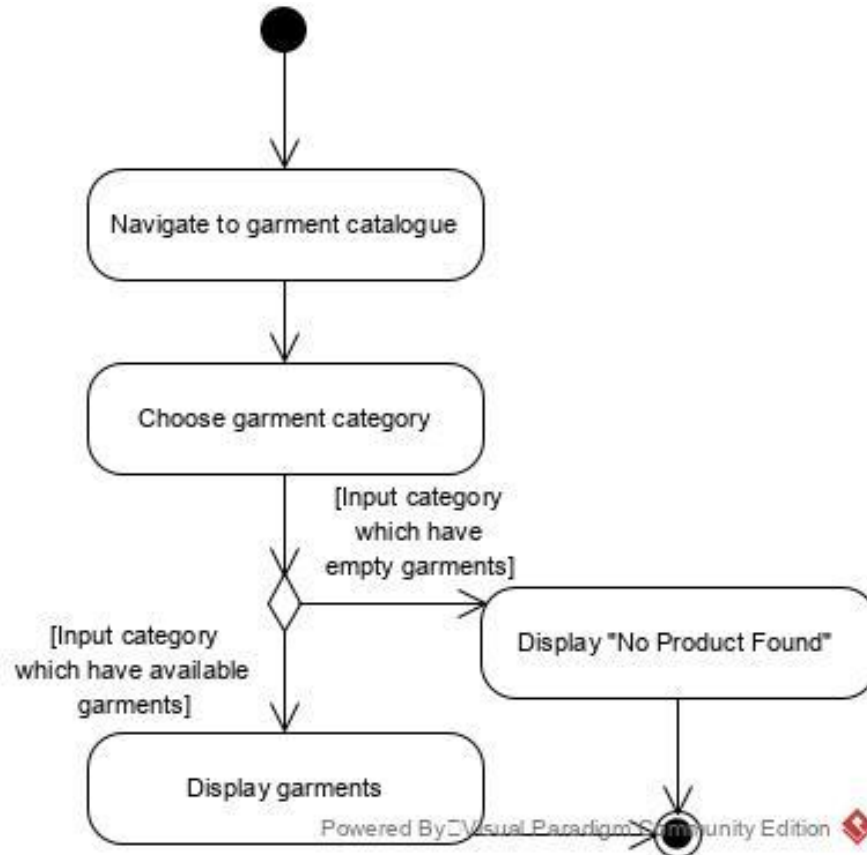


Figure 3.8 – Activity diagram for F001 Browse Garment Catalogue.

3.2.2 F002 View Garment

The following table (Table 3.3) shows the details of this feature as known as use case description, followed by an activity diagram (Figure 3.9) to illustrate the activity flow of the feature.

Table 3.3 – Use case description for F002 View Garment.

Use Case ID	UC002
Feature	F002 View Garment
Purpose	To allow user to view garment's information.
Actor	User
Trigger	User selects garment in the catalogue.
Precondition	The application is in "Running" state.

Scenario Name	Step	Action
Main Flow	1	User selects garment in the catalogue.
	2	System displays the selected garment's information.

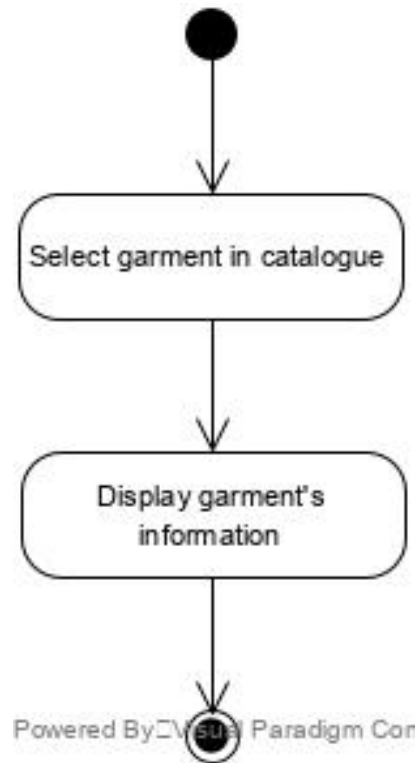


Figure 3.9 – Activity diagram for F002 View Garment.

3.2.3 F003 Capture Body Skeleton Joints

The following table (*Table 3.4*) shows the details of this feature as known as use case description, followed by an activity diagram (*Figure 3.10*) to illustrate the activity flow of the feature.

Table 3.4 – Use case description for F003 Capture Body Skeleton Joints.

Use Case ID	UC003
Feature	F003 Capture Body Skeleton Joints
Purpose	To allow user to capture body skeleton joints.
Actor	User

Trigger	User selects “Try It” on the garment’s information page.	
Precondition	<ul style="list-style-type: none"> • The application is in “Running” state. • Camera permission is granted in the application. 	
Scenario Name	Step	Action
Main Flow	1	User selects “Try It” on the garment’s information page.
	2	System requests for user’s whole body to be in the camera.
	3	User manipulates the camera, including move it or switching facing between front-facing and rear facing to let the whole body to be in the camera.
	3	System recognize and detect body skeleton joints in real-time.
	4	System displays the detected body skeleton joints in real-time.
Alternate Flow – Failed in Showing Whole Body	3.1.1	User fails to show whole body in the camera.
	3.1.3	Back to Main Flow Step 2.

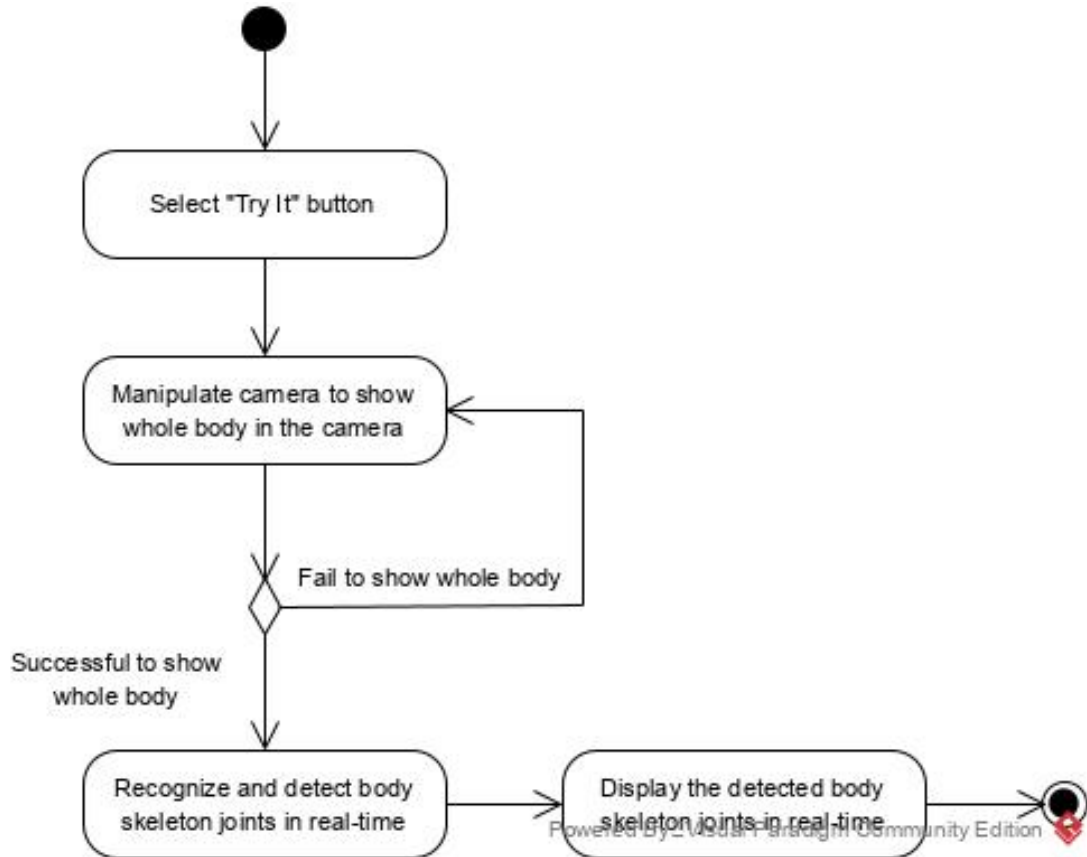


Figure 3.10 – Activity diagram for F003 Capture Body Skeleton Joints.

3.2.4 F004 Try Garment On

The following table (Table 3.5) shows the details of this feature as known as use case description, followed by an activity diagram (Figure 3.11) to illustrate the activity flow of the feature.

Table 3.5 – Use case description for F004 Try Garment On.

Use Case ID	UC004
Feature	F004 Try Garment On
Purpose	To allow user to try garment on.
Actor	User
Trigger	User captures body skeleton joints successfully.
Precondition	<ul style="list-style-type: none"> The application is in “Running” state.

	<ul style="list-style-type: none"> Camera permission is granted in the application. 	
Scenario Name	Step	Action
Main Flow	1	User captures body skeleton joints successfully.
	2	System superimposes the garment over the body.
	3	System displays the garment in real-time.

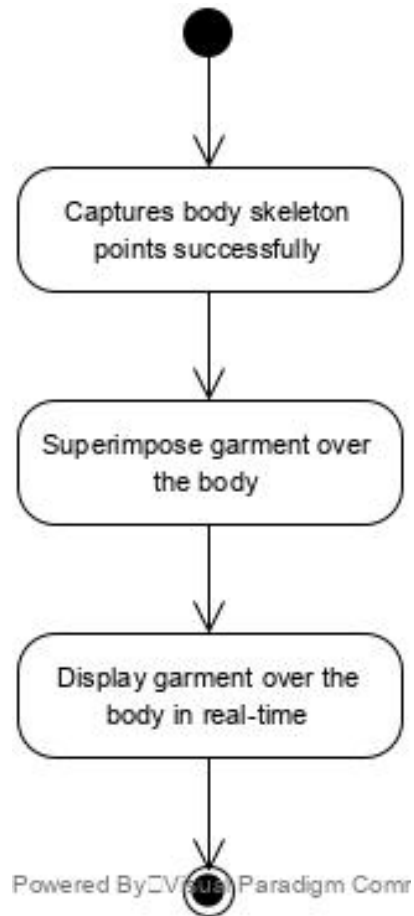


Figure 3.11 – Activity diagram for F004 Try Garment On.

3.2.5 F005 Snap Photo

The following table (Table 3.6) shows the details of this feature as known as use case description, followed by an activity diagram (Figure 3.12) to illustrate the activity flow of the feature.

Table 3.6 – Use case description for F005 Snap Photo.

Use Case ID	UC005	
Feature	F005 Snap Photo	
Purpose	To allow user to snap photo.	
Actor	User	
Trigger	User press camera icon button.	
Precondition	<ul style="list-style-type: none"> • The application is in “Running” state. • Camera permission is granted in the application. • Storage permission is granted in the application. 	
Scenario Name	Step	Action
Main Flow	1	User press camera icon button.
	2	System captures the photo of user with or without garment in real-time.
	3	System saves and displays the captured photo.
Alternate Flow – Failed Photo Saving	3.1	Photo saving failed.
	3.2	System displays “Failed to Save Photo” error message.

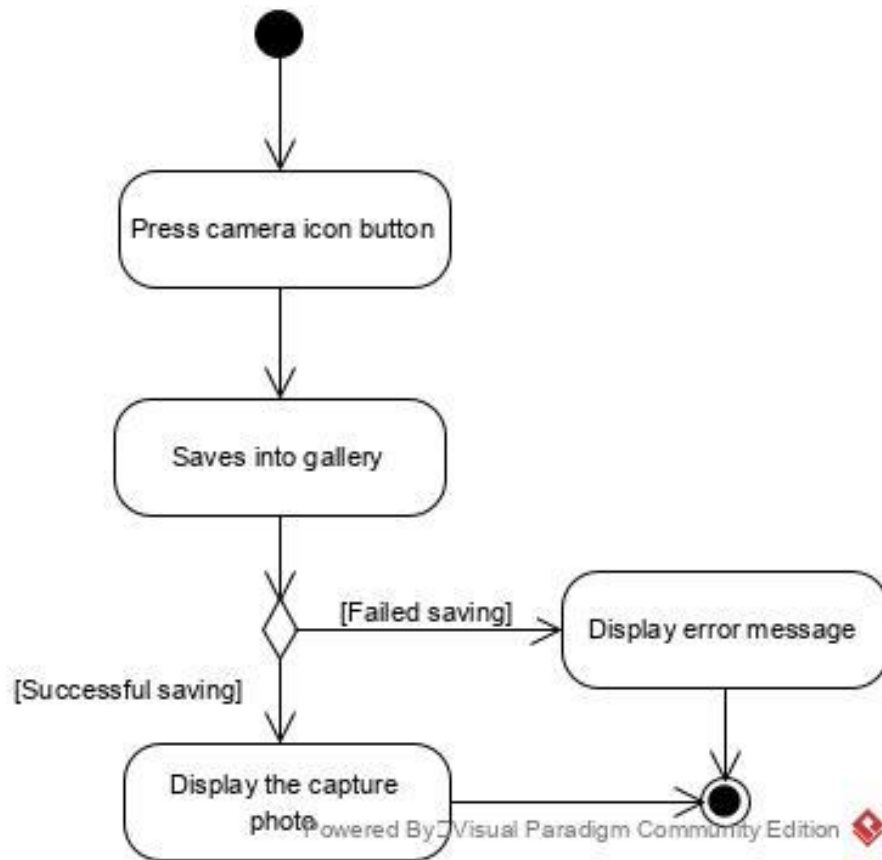


Figure 3.12 – Activity diagram for F005 Snap Photo.

Chapter 4 System Implementation

4.1 Design Specifications

4.1.1 Methodologies and General Work Procedures

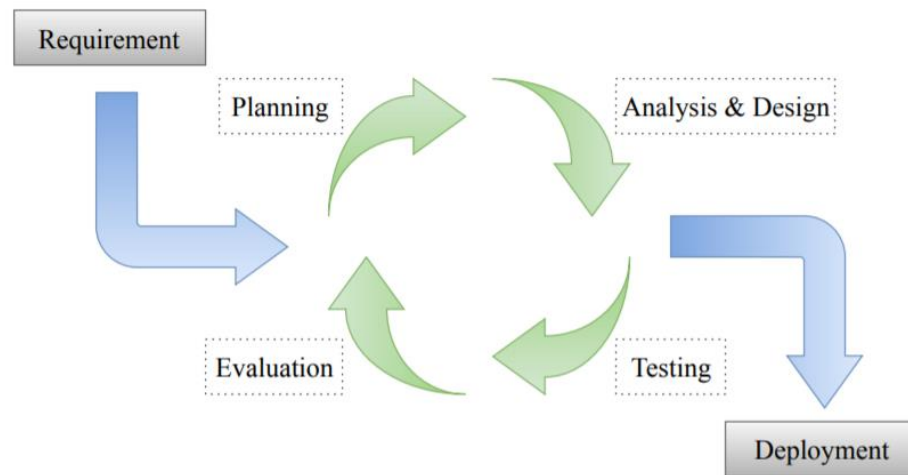


Figure 4.1 – Iterative model.

The methodology chosen to be applied in the development of AR virtual fitting room application is iterative model. Iterative model is a particular implementation of a software development life cycle (SDLC) that focuses on an initial, simplified implementation, which then progressively gains more complexity and a broader feature set until the final system is built entirely. It is an approach of breaking down the large software development process into smaller pieces. As shown in *Figure 4.1*, there are 6 main stages in iterative methodology: Requirement, Planning, Analysis and Design, Evaluation, Testing and Deployment.

The reason to choose to apply iterative model in the development is because of its high flexibility compared to other methodologies. With the methodology, a part of the application can be implemented by starting with small sets of requirements in order to adapt the ever-changing scope and requirements with minimal losses in terms of time and cost. For additional requirements, functions are added or changed to meet the requirements in

the next iteration in order to create a new version which is an improved version of previous iteration. Moreover, the application is easier to be tested and evaluated during an iteration in order to identify and manage risks. Any potential defects can be recognized quickly and reverted back to previous iteration within a short time frame. Besides, blueprint and prototype of the application can be presented to users to acquire reliable feedback which is important in improving the application. In short, the scope and requirements that were previously set can be enhanced in order to help the developers to build and deliver a quality system quickly and easily with iterative model.

4.1.2 Tools to Use

Software:

1. Open source computer vision (OpenCV)

OpenCV is the leading open source computer vision and machine learning software library of programming functions mainly aimed at real-time computer vision. OpenCV provides a common infrastructure for computer vision applications by offering several hundreds of computer vision algorithms.

2. TensorFlow Lite

TensorFlow Lite is a lightweight open source deep learning framework for on-device machine learning inference. It provides machine learning models for developers to perform classification, detection, regression and any other machine learning algorithms. It supports running the models on mobile, embedded and IoT devices with low latency and small binary file size. Currently, it is supported on Android and iOS mobile platforms via C++ API.

3. Android Studio

Android Studio is the official IDE or tool for developing applications exclusively on Google's Android mobile platforms. It helps to develop creative user

interface as it has a strong editor tool and various versions of emulators to test and simulate sensors without having actual Android devices.

4. Visual Paradigm 16.0

Visual Paradigm is a software tool that is used to model business information system and manage development process. It supports key industry modelling languages and standards such as Unified Modeling Language (UML). In this project, it is used to draw the architecture and design of the application.

5. Firebase

Firebase is a Google's developed mobile and web application development platform. There are 19 products offered by this platform such as Firebase Authentication, Firebase Cloud Storage and etc. In this project, Firebase Realtime Database is utilized to store the garment product information.

Hardware:

1. Laptop

Table 4.1 – Laptop hardware specifications.

System Type	64-bit Operating System
Processor	Intel(R) Core(TM) i7-8750H CPU @ 2.20GHz
Graphics Processor	Intel(R) UHD Graphics 630
Graphics Card	NVIDIA GeForce GTX 1050
RAM	16.0 GB DDR4 2666MHz
Operating System	Microsoft Windows 10 Pro

2. Smartphone

Table 4.2 – Smartphone hardware specifications.

Model	Huawei Mate 20 Pro
Processor	Huawei Kirin 980

	Octa-core CPU (2 @ 2.6GHz, 2 @ 1.92GHz, 4 @ 1.8GHz) Dual NPU
Graphics Processor	Mali-G76 720MHz
RAM	6GB
Storage	128GB NM (Nano memory) card slot for memory expansion
Rear Camera	<ul style="list-style-type: none"> • Main: 40MP sensor, f/1.8 aperture • Second: 8MP 3x telephoto sensor, OIS, f/2.4 aperture • Third: 20MP ultra-wide sensor, f/2.2 aperture, 16mm focal length equivalent
Front Camera	24MP RGB sensor
Software Version	Android 9.0 Pie with EMUI 9.0

4.1.3 Functional and Non-Functional Requirements

Functional Requirements:

- The system shall detect and scan one user's body including head, upper and lower parts through smartphone camera.
- The system shall obtain and process human body skeleton joint positions information and body measurements.
- The system shall display garment collections for user to select.
- The system shall superimpose selected garment over user's body.
- The system shall allow user to change garment.
- The system shall allow user to take a picture of himself/herself with the garment.

Non-Functional Requirements:

- The system shall be able to run on Android platform.

- The system shall be able to detect and scan human body in various type of environmental condition such as low brightness.
- The system shall be able to detect and scan human body within 1 second.
- The system shall be able to fit garment onto human body within 2 seconds.

4.1.4 System Performance Definition

In this project, the system requires accurate body skeleton joint positions and body measurements for fitting garment to human body seamlessly to create a realistic image of how garment looks on human body. Hence, the accuracy of human body detection and scanning system should be high to achieve the goal.

Besides, model of garment should have correct information including size and style of the actual garment. This is to avoid misleading users to purchase garment with inadequate size, fit or style.

Furthermore, the mobile application should be run with minimal latency to avoid user dissatisfaction. For instance, users will not choose to use the application due to its low speed performance as it does not make any contribution to time advantages for them. Hence, the system should be able to detect human body and apply garment on it within a very short time frame.

4.2 Prototype

4.2.1 Mobile Application Interface



Figure 4.2 – App icon.



Figure 4.3 – App splash screen.

Figure 4.2 shows the app icon of the proposed application, named as “Fit”. The app icon is a visual anchor of the product to allow it to look attractive and outstanding in order to be differentiated from other applications. *Figure 4.3* shows the splash screen interface of Fit AR fitting room application. It act as a boot screen to notify the users that the application is in the process of loading once the application is launched. Furthermore, splash screen consists of the logo of the product to deliver brand information to the users.

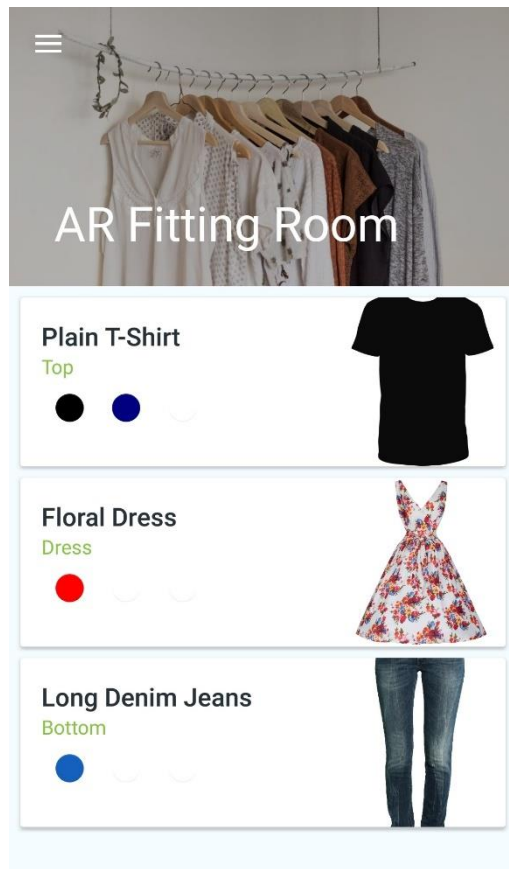


Figure 4.4 – App home page and garment catalogue interface.

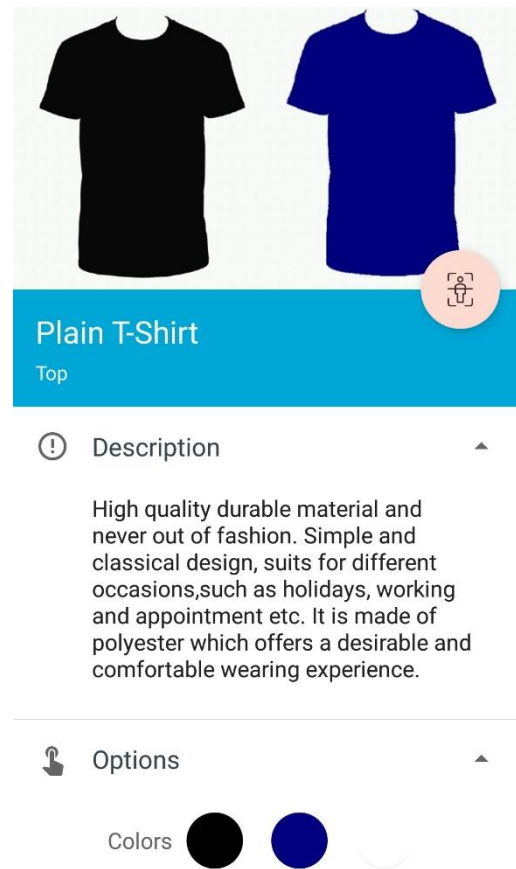


Figure 4.5 – App product details interface.

As shown in *Figure 4.4*, the available garments are placed in a list, called catalogue that users can select one of it to perform further action. Each item in the catalogue consists of garment's image, title, category and options of colors. On the other hand, *Figure 4.5* shows the interface of product details page. Users can navigate to this page by pressing on one of the item in the catalogue. The product details page contains garment information including cover image, title, category, description and options of colors. The “Try It” button at the right bottom of the cover page is designed for user to press on it in order to try the garment on virtually using AR.

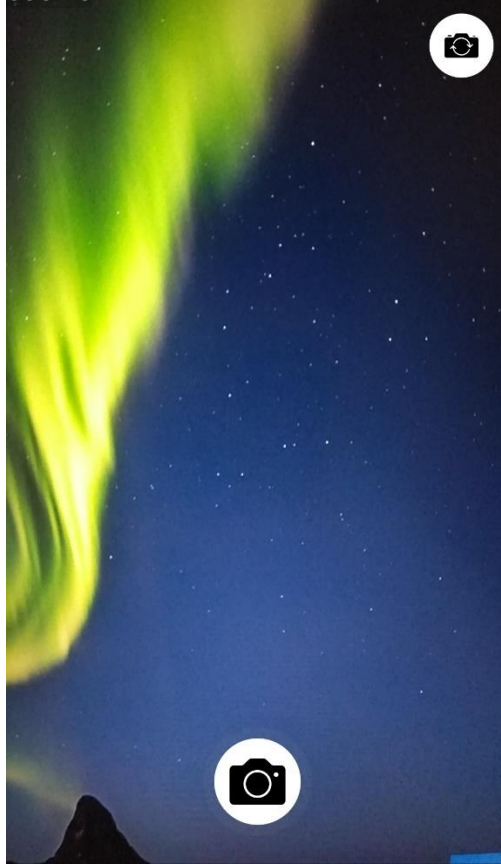


Figure 4.6 – App camera preview interface without detected body skeleton joints.

Camera preview interface of the application without detected body skeleton joints is shown in *Figure 4.6*. The camera switching button at the right upper side of the application is designed to let user to switch the facing of camera including front and back facing by pressing on it. Furthermore, user can capture photo by pressing on the camera button at the bottom of the interface. User is able to snap photo of themselves with or without garment for reference purpose in the future.



Figure 4.7 – App camera preview interface with detected body skeleton joints.



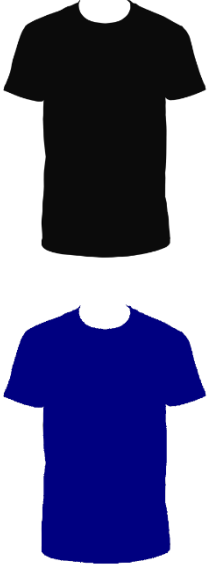

Figure 4.8 – App camera preview interface with garment model superimposed over body.


Figure 4.7 shows the camera preview interface with body skeleton joints positions once they are successfully detected. Users are allowed to capture and view the skeleton joints positions by showing whole body in the camera in real-time. In addition, users can try the garment on by pressing on any position of the screen. In a result, *Figure 4.8* shows the camera preview with garment model superimposed over the body.

4.2.2 Garment Model

This following table (*Table 4.3*) details the customized garment models for the application.

Table 4.3 – Customized garment models.

Garment Model	Description
 <p><i>Figure 4.9 – Garment model 1.</i></p>	<p>Title: Plain T-Shirt</p> <p>Category: Top</p> <p>Description: High quality durable material and never out of fashion. Simple and classical design, suits for different occasions, such as holidays, working and appointment etc. It is made of polyester which offers a desirable and comfortable wearing experience.</p> <p>Colors: Black, Navy Blue</p>
 <p><i>Figure 4.10 – Garment model 2.</i></p>	<p>Title: Floral Dress</p> <p>Category: Dress</p> <p>Description: A mini sexy dress with V-neck and no sleeves. The floral design features, high waist lace-up, temperament commuting casual style are able to keep the fashion trend. The fabric is breathable and comfortable which is made of high-quality materials, trendy and fashionable to make you more energetic.</p> <p>Colors: Red</p>

 <p data-bbox="331 590 561 674"><i>Figure 4.11 – Garment model 3.</i></p>	<p data-bbox="621 197 941 231">Title: Long Denim Jeans</p> <p data-bbox="621 283 860 317">Category: Bottom</p> <p data-bbox="621 369 1414 678">Description: The pants are made of high quality fabric which is cotton denim which has great hand feel. You are able to move around and bend as much as you want with their comfort and stretchable fabric. Exclusive design slims, shapes and flatters for the slimmer look you love. Simply put them on and get ready for work.</p> <p data-bbox="621 730 789 764">Colors: Blue</p>
--	--

4.3 Implementation Issues and Challenges

During the development of AR virtual fitting room application, the main issue faced is the lack of processing power of smartphone. Although smartphones are getting more powerful nowadays, they are still unable to offer comparable performance to personal computer (PC)'s processor. In this way, some of the advanced computer vision technologies are not able to be applied in this project in order to improve performance in terms of speed and accuracy.

Besides, as the AR technology is still considered as new to society, the online documentations of some of the tools that support developing an AR application are incomplete. Therefore, extra effort has to be put on researching of the ways to utilize the tools and implement them in the application. The time required to do research causes the whole progress of the project to be slowed down.

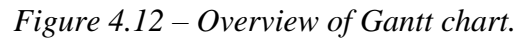
In addition, the lack of garment model dataset is also one of the issues faced during the development. In order to superimpose the garment over human body, the garment model have to be customized in order to match with the human body skeleton joint positions.

4.4 Timeline

The project development is planned from start to finish using Gantt chart as shown in *Figure 4.12*. It shows the past, current and future progresses of the project based on the methodology phases: Requirement, Planning, Analysis and Design, Implementation and Testing, Deployment.

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In requirement stage as shown in *Figure 4.13* the requirements of the system are gathered, analysed and interpreted. The functionality, performance levels and other characteristics which the application needs to satisfy for it to be acceptable are identified.

Project Start Date		9/30/2019 (Monday)		Display Week		1		Week 1						
Project Lead		Loh Cheak Ling						30 Sep 2019						
								30	1	2	3	4	5	6
								M	T	W	T	F	S	S
1	Requirement	Mon 9/30/19	Fri 10/04/19	5	100%									
1.1	Gather requirements	Mon 9/30/19	Wed 10/02/19	3	100%									
1.2	Analyse and interpret requirements	Thu 10/03/19	Fri 10/04/19	2	100%									

Figure 4.13 – Requirement stage in Gantt chart.

In planning stage as shown in *Figure 4.14*, the problem statement, project scope and objectives as well as the proposed solution to solve the problem statement are determined.

Project Start Date		9/30/2019 (Monday)		Display Week		2		Week 2						
Project Lead		Loh Cheak Ling						7 Oct 2019						
								7	8	9	10	11	12	13
								M	T	W	T	F	S	S
2	Planning	Mon 10/07/19	Sat 10/12/19	6	100%									
2.1	Define problem statement	Mon 10/07/19	Wed 10/09/19	3	100%									
2.2	Define project objectives	Thu 10/10/19	Sat 10/12/19	3	100%									
2.3	Define project scope	Thu 10/10/19	Sat 10/12/19	3	100%									

Figure 4.14 – Planning stage in Gantt chart.

In analysis and design stage as shown in *Figure 4.15*, reviews on existing systems and technology are done for comparison in order to develop a better concept for a new system. The strengths and weaknesses of each reviewed system are identified. Overall system design along with physical, architectural, interface, and file and program designs should be completed in this stage.

Chapter 4 System Implementation

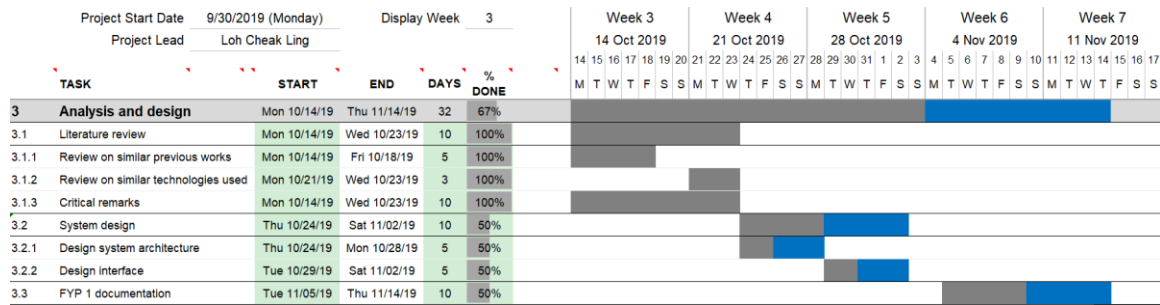


Figure 4.15 – Analysis and design stage in Gantt chart.

In implementation and testing stage as shown in *Figure 4.16*, all the pieces of code are integrated and deployed in the testing environment. The system is also examined for improvement in order to deliver a quality system.

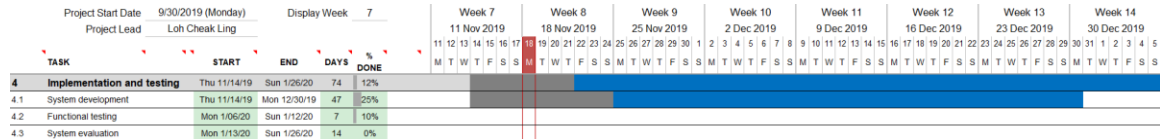


Figure 4.16 – Implementation and testing stage in Gantt chart.

In deployment stage as shown in *Figure 4.17*, the system is ready for the deployment and ready to go live. The whole processes of system development are documented.

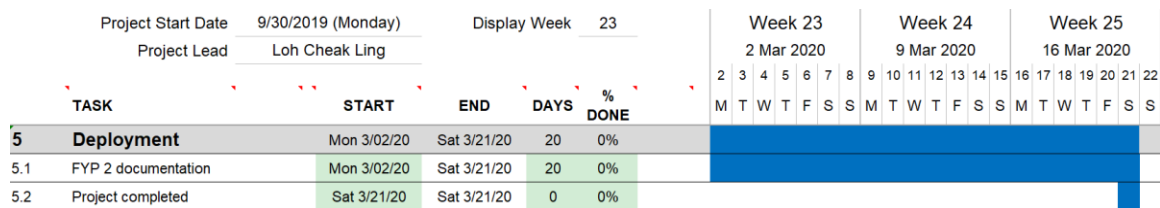


Figure 4.17 – Deployment stage in Gantt chart.

Chapter 5 System Testing

5.1 Verification and Validation

5.1.1 Verification Plan

The AR virtual fitting room is developed to allow users to virtually try clothing on based on augmented reality and computer visioning. The system should be able to recognize and detect human body in order to obtain body skeleton joint positions and body measurements in most of the common condition types. The system should also be able to fit garment onto human body in real-time through smartphone camera. In order to verify the functionalities of the system, a few of tests in different situations are planned to be carried out after the system is developed. The verifications plans are shown in *Table 5.1*, *Table 5.2* and *Table 5.3*.

1. Simple scene

A user is surrounded with simple and blank background. The system is required to detect user's body skeleton joint position and fit garment onto user's body in real-time.

Table 5.1 – Verification plan T1.

Procedure Number	T1
Method	Testing
Applicable Requirements	Detect user's body skeleton joint position and fit garment onto user's body in real-time.
Purpose / Scope	To detect human body and fit garment onto human body in simple scene.
Items Under Test	Live video
Precautions	<ul style="list-style-type: none"> The user should expose whole body to smartphone camera.
Special Conditions/Limitations	<ul style="list-style-type: none"> If the exposed human body is partial, the system may not be able to detect the human body accurately.

Equipment/Facilities	Android smartphone with software version Android 7.0+
Data Recording	None
Acceptance Criteria	The system fits garment onto human body or do not display garment.
Procedures	<ol style="list-style-type: none"> 1. Open camera. 2. Select garment. 3. Expose whole body to camera. 4. The system fit garment onto user's body.
Troubleshooting	Repeat the procedure.
Post-Test Activities	None

2. Cluttered Scene

A user is surrounded with other different types of object. The system is required to detect user's body skeleton joint position and fit garment onto user's body in real-time.

Table 5.2 – Verification plan T2.

Procedure Number	T2
Method	Testing
Applicable Requirements	Detect user's body skeleton joint position and fit garment onto user's body in real-time.
Purpose / Scope	To detect human body and fit garment onto human body in cluttered scene.
Items Under Test	Live video
Precautions	<ul style="list-style-type: none"> • The user should expose whole body to smartphone camera.
Special Conditions/Limitations	<ul style="list-style-type: none"> • If the exposed human body is partial, the system may not be able to detect the human body accurately.
Equipment/Facilities	Android smartphone with software version Android 7.0+
Data Recording	None

Acceptance Criteria	The system fits garment onto human body or do not display garment.
Procedures	<ol style="list-style-type: none"> 1. Open camera. 2. Select garment. 3. Expose whole body to camera. 4. The system fit garment onto user's body.
Troubleshooting	Repeat the procedure.
Post-Test Activities	None

5.1.2 Verification Result and Analysis

After designed the verification plans that are mentioned in Section 5.1.1, the plans are carried out to test the developed application. Each of the verification results will be analysed and interpreted as well as explained in details.

1. Simple scene



Figure 5.1 – Detect body skeleton joint positions in simple background.



Figure 5.2 – Fit garment onto body in simple background.

As shown in *Figure 5.1*, the application displays the detected body skeleton joint positions based on the pose estimation result returned by the pose estimation model. Based on the real-time video of body in simple background, the application is **able** to recognize, detect and track the body. In this case, it proves that the model has a good accuracy in recognizing, detecting and tracking body skeleton joint positions.

Based on *Figure 5.2*, the application superimposes the virtual garment over the body after successfully extracted the body skeleton joint positions. Based on the real-time video of body in simple background, the application is **able** to fit the virtual garment onto the detected body in an appropriate way. In this case, it proves that the application succeeds in presenting the visualisation of wearing garment for user.

2. Cluttered scene



Figure 5.3 – Detect body skeleton joint positions in cluttered background.



Figure 5.4 – Fit garment onto body in cluttered background.

As shown in *Figure 5.3*, the detected body skeleton joint positions are displayed on the camera preview interface of the application in real-time. Although the body is surrounded with other different objects, the application is still **able** to recognize, detect and track the body as well as obtain the pose estimation result returned from the model after classified the frame of the live video. As a result, it proves that the application has a high accuracy in body skeleton joint positions detection.

According to *Figure 5.4*, the camera preview interface shows the successful result of fitting virtual garment onto the body. Although the body is surrounded with other different objects, the application is still **able** to superimpose the virtual garment over the

detected body in a correct way. As a result, it proves that the application is successful in enabling user to be virtually appeared like wearing clothing on the camera preview interface.

5.2 Black Box Testing

According to the features of application, risk level can be classified into 3 level: low, medium and high. Basically, high indicates that the effect of the risk for the feature would be very high and even non-tolerable. Medium risk level is tolerable but not desirable for the application although the risk is limited, while low risk level is tolerable. In order to prevent loss, feature with high risk level should be prioritized to test compared to the others. The following table (*Table 5.3*) contains the feature to be tested based on Section 3.3. Listed together are the feature ID and its corresponding descriptions, estimated risk level and test level.

Table 5.3 – Features to be tested.

Feature ID	Feature Description	Risk Level	Test Level
F001	Browse Garment Catalogue	High	System
F002	View Garment	High	System
F003	Capture Body Skeleton Joints	High	System
F004	Try Garment On	High	System
F005	Snap Photo	Medium	System

5.2.1 Use Case Testing

Use case testing is one of the black box testing techniques which is used to test functional parts of the system. In this project, use case testing is suitable to be applied on testing all of the features of the application based on Section 3.3. This section details all test cases designed for each of the application features.

Table 5.4 – Use case testing for F001 Browse Garment Catalogue.

Feature ID	F001		
Objective	Browse Garment Catalogue		
Condition	Set Up	Expected Result	Pass/Fail
Main Flow	1. User navigates to garment catalogue 2. User chooses “Top” category.	System displays the available garments.	Pass
Alternate Flow – No Garments in the Selected Category	1. User navigates to garment catalogue. 2. User chooses “Romper/Jumpsuits” category.	System displays “No Product Found”.	Pass

Table 5.5 – Use case testing for F002 View Garment.

Feature ID	F002		
Objective	View Garment		
Condition	Set Up	Expected Result	Pass/Fail
Main Flow	1. User selects “Plain T-Shirt”.	System goes to garment details page and displays the garment’s information.	Pass

Table 5.6 – Use case testing for F003 Capture Body Skeleton Joints.

Feature ID	F003		
Objective	Capture Body Skeleton Joints		
Condition	Set Up	Expected Result	Pass/Fail
Main Flow	1. User selects “Try It” on the garment’s information page. 2. System requests for user’s whole body to be in the camera. 3. User switches to back camera and show whole body in the camera. 4. System recognize and detect body skeleton joints in real-time.	System displays the detected body skeleton joints in real-time.	Pass

Alternate Flow – Failed in Showing Whole Body	<ol style="list-style-type: none"> 1. User selects “Try It” on the garment’s information page. 2. System requests for user’s whole body to be in the camera. 3. User switches to back camera and does not show whole body in the camera. 4. System fails to recognize and detect body skeleton joints in real-time. 	System requests for user’s whole body to be in the camera.	Pass
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Table 5.7 – Use case testing for F004 Try Garment On.

Feature ID	F004		
Objective	Try Garment On		
Condition	Set Up	Expected Result	Pass/Fail
Main Flow	<ol style="list-style-type: none"> 1. User captures body skeleton joints successfully in real-time 2. System superimposes the garment over the body in real-time. 	System displays the garment fitted onto the body in real-time.	Pass

Table 5.8 – Use case testing for F005 Snap Photo.

Feature ID	F005		
Objective	Snap Photo		
Condition	Set Up	Expected Result	Pass/Fail
Main Flow	1. User presses camera icon button. 2. System captures the photo of user with or without garment in real-time. 3. System saves the photo into phone storage.	System displays successful message.	Pass
Alternate Flow – Failed Photo Saving	1. User presses camera icon button. 2. System captures the photo of user with or without garment in real-time. 3. System fails to save the photo into phone storage.	System displays “Failed to Save Photo” error message.	Pass

Chapter 6 Conclusion

6.1 Project Review, Discussions and Conclusions

Recent advancements in online shopping has enabled customers to purchase items anywhere and anytime. Although there are several advantages of online shopping, but there is one huge problem that stops most people from shopping online, which is unable to try things on especially for clothing.

On the other hand, clothing shopping may be a tedious and troublesome for some in-store customers which does not wish to waste time in the fitting room. In fact, both of the online and in-store customers wish to check whether the clothing fits in size and style in a more time-saving, efficient and convenient way. Hence, this project aims to develop an AR virtual fitting room for customers to perform clothing fitting without physically trying it on body.

In this project, the AR virtual fitting room application is designed to be lightweight and efficient that can be run on inexpensive hardware which is Android smartphone. Hence, users are allowed to experience AR and the body detection system by only installing the mobile application instead of whole system. In addition, the Graphical User Interface (GUI) of the application is simple and easy to use to make it applicable to people in all age groups. Users are able to get started with it quickly and easily.

Basically, human body is detected, recognized and tracked using smartphone camera in order to interact with the application content in real-time. Pose estimation is implemented to detect human body skeleton joint positions so that body movements can be tracked over the time. The body measurements can be obtained by calculating the distance between each of the skeleton joints detected. Then, the model of garment is fitted to the human body based on the body skeleton joint positions, body measurements as well as the garment measurements.

The application is developed with great system performance in terms of accuracy to avoid misleading users to purchase garment with inadequate size, fit or style. The time

needed for human body detection and fitting the garments onto the human body is short to attain convenient purpose. Besides, the application supports detecting human body in various type of environmental conditions such as low brightness, cluttered scene and etc. so that users are able to try clothing on anywhere and anytime. As a result, the objectives mentioned are achieved.

6.2 Future Work

In this project, the proposed application has achieved the objective stated and solved the main problem that is currently met by most of the customers who like to shop online. Customers are allowed to check for fit, size or style while shopping online by using the application to try garment on virtually using AR. Although the application is said to have brought a lot of benefits to E-shopping industry, there are some improvements that can still be made to develop a better version of application in terms of convenience, accuracy and interaction.

For future plan, recommendation system can be introduced to provide recommendations of clothing according to user's purchased history or wish list. The garments which users are most likely to purchase should be shown prior to the unlikely ones in order to enhance customer experience.

Apart from that, body segmentation technology can be applied to increase more body measurements such as waistband, back length and etc. to improve the accuracy of fitting garment onto the body. In addition, after user selected a garment to virtually try it on his or her body, an information about the sizing of the garment such as overfitting or perfectly fit should be displayed to inform the user.

Furthermore, motion capture system can be added into the application in the future. It is to allow users to use hand motions to interact with the application content without having to return to mobile device in order to perform operation in a more convenient way. By using this motion capture system, users are able to browse the various options of the garment by just moving arms above head.

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Virtual Fitting Room

AR⁺

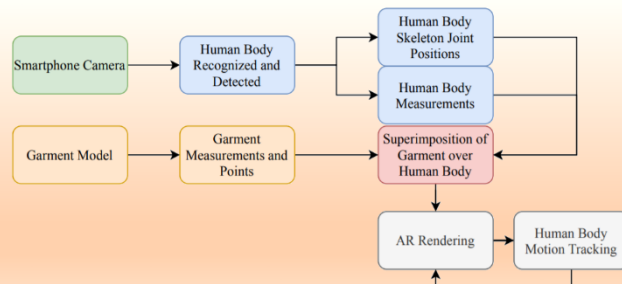
Introduction

AR virtual fitting room is equivalent to an in-store fitting area that is designated for customers to put on a piece of clothing before deciding whether to purchase it. It allow shoppers to visualize how clothing looks and fits on their bodies in real-time.



How it works?

Through the smartphone camera, the virtual garment is fitted onto the body after obtained body skeleton joint position and body measurements of the body in real-time.



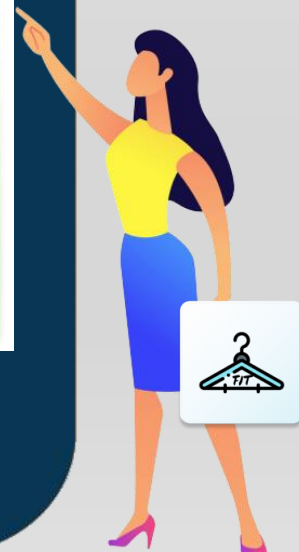
Results

(Example in Real-Time)



Conclusion

The application enhances the way customer shop and helps them to choose suitable clothing. It is also believed to enhance customer experience in clothing fitting by enabling customers to virtually try clothing on in order to check for size, fit or style.



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Chapter 1 Introduction

1.1 Problem Statement and Motivation

With the advanced technology growth, online shopping as known as e-shopping has grown exponentially throughout the world nowadays. Advances in e-shopping has driven a shopping revolution where customers are able to purchase items anywhere and anytime.

Despite the benefits of e-shopping, there are some disadvantages which deter customers from purchasing items online. The most common problem faced by online customers is unable to try things on especially for clothing. Most of the them wish to check whether the clothing fits in size as sometimes the purchased clothing does not match with the size description provided by the seller. Offering return policies or free shipping for returns is aim to compensate for inadequate fit and sizing content but it will bring much inconvenience to the seller.

Furthermore, some of the customers may prefer to shop in-store in order to try clothes on so that they can know whether the clothing fits them or not. However, for popular clothing store, the fitting rooms are usually full and there are long queues at peak hours especially holidays. Customers may need to queue up for a long time just to try few clothes on, thus lead to customer dissatisfaction.

In fact, customers will choose one or both of the clothing shopping styles which are online shopping and in-store shopping based on their specific demands. However, both of the ways are unable to achieve a goal which is allowing customers to check for size, fit or style of their favourite clothing without physically trying it on body. Therefore, an AR virtual fitting room is proposed in this project in order to help customers to accomplish their shopping goals.

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✓	Abstract
✓	Table of Contents
✓	List of Figures (if applicable)
✓	List of Tables (if applicable)
	List of Symbols (if applicable)
✓	List of Abbreviations (if applicable)
✓	Chapters / Content
✓	Bibliography (or References)
✓	All references in bibliography are cited in the thesis, especially in the chapter of literature review
	Appendices (if applicable)
✓	Poster
✓	Signed Turnitin Report (Plagiarism Check Result - Form Number: FM-IAD-005)

*Include this form (checklist) in the thesis (Bind together as the last page)

<p>I, the author, have checked and confirmed all the items listed in the table are included in my report.</p>  <p>(Signature of Student)</p> <p>Date: 23/04/2020</p>	<p>Supervisor verification. Report with incorrect format can get 5 mark (1 grade) reduction.</p>  <p>(Signature of Supervisor)</p> <p>Date: 23/04/2020</p>
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