An ICT Based Solution for Virtual Garment Fitting in for Online Marketplace

By

M.D.H.E.Gunatilake
2013/IS/018

D.D.Hidellaarchchi
2013/IS/020

W.M.I.C.S.Perera
2013/IS/036

This dissertation is submitted to the University of Colombo School of Computing
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University of Colombo School of Computing
35, Reid Avenue, Colombo 07,
Sri Lanka
December 201

Declaration

I, *M.D.H.E.Gunatilake (2013/IS/018)* hereby certify that this dissertation entitled *An ICT Based Solution for Virtual Garment Fitting in for Online Market Place* is entirely my own work and it has never been submitted nor is currently been submitted for any other degree.

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<Date> <Student's Signature>

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<Date> <Student's Signature>

I, *W.M.I.C.S.Perera (2013/IS/036)* hereby certify that this dissertation entitled *An ICT Based Solution for Virtual Garment Fitting in for Online Market Place* is entirely my own work and it has never been submitted nor is currently been submitted for any other degree.

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<Date> <Student's Signature>

I, *Dr. K.D.Sandaruwan* certify that I supervised this dissertation entitled *An ICT Based Solution for Virtual Garment Fitting in for Online Market Place* conducted by *M.D.H.E.Gunatilake, D.D.Hiddellaarchchi, W.M.I.C.S.Perera* in partial fulfillment of the requirements for the degree of Bachelor of Science Honours in Information Systems.

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<Date> <Signature of Supervisor>

Abstract

There is a considerable online shopping rate corresponding to apparels, yet high return rate is visible in online apparel purchases. Size mismatch is a major reason behind the issue of returning apparels purchased online. In the context of virtual fitting, there are many 3D applications to check the fitness of a particular garment to a specific user. The applicability of these 3D solutions for the online marketplace is comparatively low since they require high user intervention and high computational power. Hence 3D solutions cannot be easily used to obtain a real time result for the online marketplace, even with their ability to provide accurate outcomes regarding the fitness of a garment.

This research presents a lightweight solution which supports the decision making process of an end user in order to select properly fitted cloths by considering human body properties and garment properties. A fitting model is proposed by incorporating the 2D patterns of the human body and the finished garment and is successfully demonstrated in this research. The fitting model has the capability of identifying the fitness of seven predefined areas of the body namely shoulder length, chest, stomach, hip, sleeve length, sleeve tightness and shirt length. The scope of the research has been limited to the generation of a fitting model for short sleeve men's shirts due to the limited time frame. An experiment has conducted to discover the best method for generating 2D block pattern from a finished shirt which identified the standard error values associated in the conversion between finished shirt and 2D block pattern. These error values were generalized and used for generating the fitting model. User preference regarding fitness priority and distance ease values have been incorporated to the fitting model.

A prototype system was implemented based on the proposed methodology and satisfactory outcomes have been obtained. A survey has been carried out to identify the aspects related to segmentation of a shirt based on prioritizing fitness areas. Qualitative approaches were used to evaluate the implemented model and it was found that implemented system performs with an accuracy of 81.2%. A user evaluation survey was conducted to find out the effectiveness of the proposed visualization techniques and 76% of the participants agreed to the fact that the current visualization system is suitable to determine the fitness of the garment. The research methodology is scalable to other garment items and other genders though the research was conducted only for short sleeve men's shirts.

Acknowledgement

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Abbreviations

3D	Three-dimensional
2D	Two-dimensional
CAD	Computer-aided Design
CPU	Central Processing Unit
ICT	Information and Communication Technology
S/W	Software

Chapter 1

Introduction

1.1 Motivation

Nowadays, people are attracted towards online shopping which is more convenient, since in-store shopping is known as one of the most time-consuming activities at present. According to statistics, 74% of world population purchase goods and services online whereas 64% of them in the age category of 24-35 focus more on buying apparel [1]. In spite of this high percentage, most of online shopping stores for clothes cause customer dissatisfaction due to several factors. The major reason behind this situation is the inability to provide perfectly fitting garments for the shoppers and the mismatch between garment qualities along with the customer expectations. Therefore, the above circumstances have accelerated the return rate of the online shopped garment items. The following statements of industry personnel validate that there is a considerable return rate for the apparels purchases made online. According to Chris Dunn, Director of Operations at TrueShip, LLC, “One out of every three apparel purchases made online is returned” [2]. According to Tracy Maple, Managing Editor of Digital Content at Online Retailer, “30% of return rate from online purchased garment items are expected by the analysts” [3]. According to Bill Briggs, Senior Editor at Online Retailer, “On average, data compiled from about 50 Kurt Salmon clients shows that online consumers return 20% to 30% of orders of apparel and other soft goods, with women usually at the high end of that range, and men at the low end” [4].

In addition to these statements, it has been clearly shown through various surveys and articles that there is an issue with the best-fit of online purchased garment items. A survey was conducted in 2014 among online merchants in Germany regarding the return rate of goods. 36.1 percent of surveyed online merchants selling fashion and accessories stated the rate of returns was at 20 percent or higher in 2014 [5]. Moreover, the results of the survey shows clothing has the highest return rate of all items purchased online as size and fit can be difficult for consumers to judge online, leading shoppers to purchase multiple sizes and colours to try on before returning those which do not suit. E-retail consultancy Javelin Group suggests these types of purchases account for around 30 percent of all clothing returns [6]. A major cost-related problem the industry is facing is the high return rate from their online sales. Returns add costs and complexity, and depress customer satisfaction and sales. Nearly 20-30% of apparel orders are being returned by the online consumer [4]. The cost to handle each return order for re-packaging, shipping, and restocking varies, ranging from $3 to $12 per order [7]. Considering that close to 70% of returns are fit related [8], the apparel industry is focused in improving the virtual fitting experience for consumers. To date, the problem of returns for apparel companies has raised to $1.4 billion US dollars [8].

The following statements prove that apart from the issues in the global context, this has become an issue in Sri Lankan context as well which is the main motivation for us to study this area. According to Yashora Abeydeera, Digital Marketing Executive of Kelly Felder "The returning rate of online purchased items is 20-30%, and more than 10% is due to fitting problems" [9]. Sajith Jayasekara, Manager, e-Commerce of Odel Private Limited also stated "80% from the returned garment items belongs to female consumers" [10].

Considering the aforementioned facts we could interpret that in general, the nature of human beings is to find the "Best-fit" irrespective of the circumstances even when purchasing apparels online. This situation has led to a major issue in the apparel industry causing loss of revenue. This research was conducted focusing on the above stated garment fitting issue in online apparel industry.

1.2 Problem Statement

Nowadays people purchase garments online due to their busy lifestyle. It is visible that these online purchases have a considerable return rate. The main reason behind this situation is the size mismatch. There are many accurate computationally intensive 3D solutions to check the fitness of a garment with the human body. The problem associated with these 3D solutions is that we cannot use them to obtain a real time result for the online marketplace since they require human intervention and 3D mesh models of users and apparels. Further, there will be large number of users who will be accessing the system concurrently to check their fitness with a dress. Even though the available 3D solutions will provide an accurate solution, the time consumed by the 3D solutions to deliver the solution will be very high. An online marketplace will require a quick solution and the available 3D solutions will not be appropriate to fulfil this requirement. Therefore there is a need for a lightweight solution which will support the decision making of the end user in order to select the properly fitted dress by considering human body properties and garment properties.

1.3 Research Questions

1. How to generate the standard 2D pattern of the finished garment item?

Generation of garment items using 2D block patterns is the common known procedure which is available in the existing literature. But, the main question is to convert a given garment item to its 2D block pattern. The pattern makers and fashion designers do not use any standard process for this conversion. And also, there aren't any standard procedure in the existing literature for converting a given garment to its 2D block pattern. Therefore solving this research question is an important part of this research study since 3D solutions are shown to be very unsuitable and ineffective for an online environment.

2. How to compare 2D patterns of human body and finished garment item?

2D patterns of human body and finished garment item act as the basis of this research study. Since there can be different methods to compare these 2D block patterns, it is necessary to identify the most suitable way of carrying out this comparison process. The selected method should be able to output necessary values that provide sufficient information which are required in the final visualization. Since this comparison process directly affects the final visualization, 2D pattern of the human body should be correctly compared with the 2D pattern of the finished garment.

3. How user preference and distance ease can be incorporated to the fitting model and the final output?

We have to consider the customer preference when deciding the fitness of a garment with the human body. Some customers prefer to wear garments which are fitting perfectly whereas some others desire to wear garments which are loosely fitting. Therefore customer preference requires an utmost significance when defining the fitness of the garments. The distance ease distribution among human body and garment will be acknowledged under this study in order to render a nearly accurate representation of the fit of garment against human body. Many researchers have considered clothing fit preferences such as tight fit, normal fit and loose fit, and have assigned distance ease values for these. The variations among distance ease values in each research have revealed the requirement of analysing the relationship of these values with the shopper's fit preferences which will be addressed as a part of this research.

4. What is the most satisfactory way to visualize the fitness of selected garments to the end user/shopper with the consideration of material properties of the garment?

Finally there should be an ideal way to display the fitness of selected garment to the end user, after finding out the best fitting garment by identifying the relationship between human body measurements and the measurements of garment and by considering user preference regarding distance ease. User should be able to get a clear view on the fitness of the garment without any confusion. Furthermore the visualization process should facilitate the decision making process of the end users. Even though 3D clothing simulation is able to represent fitness of garments accurately, the fact that it requires more time and bandwidth has diminished the customer satisfaction on retrieving the final output briskly and comfortably. Considering all the aforementioned aspects the following study is carried out to present the final result to the online user in a more convenient manner by maintaining a high percentage of accuracy.

1.4 Research Approach

We used the existing literature to identify the human body measurements which are being used to model a human body properly as well as standard measurements of garment items that are being used in apparel industry. Furthermore, we used the existing literature to determine material properties of a garment and distance ease values. The users of the proposed solution will be provided with an option to choose their preference regarding the distance ease apart from entering their body measurements to the proposed system.

In the proposed approach the 2D patterns of both human body model and the selected garment item model were taken into consideration. By comparing these two patterns which are in same platform, the solution is delivered to the end user. This comparison is accomplished with less computational power and less user intervention in order to identify the best fitting garment to the end user using the comparison between the two patterns as well as user preference regarding distance ease values.

Accuracy validation of the proposed solution was done as the final step. We have elucidated the accuracy of the suggested solution by applying it directly to the human users and using the available three-dimensional garment fitting models. Furthermore the proposed solution provided enhancements to the existing literature.

Figure 1.1 illustrates the aforementioned process.

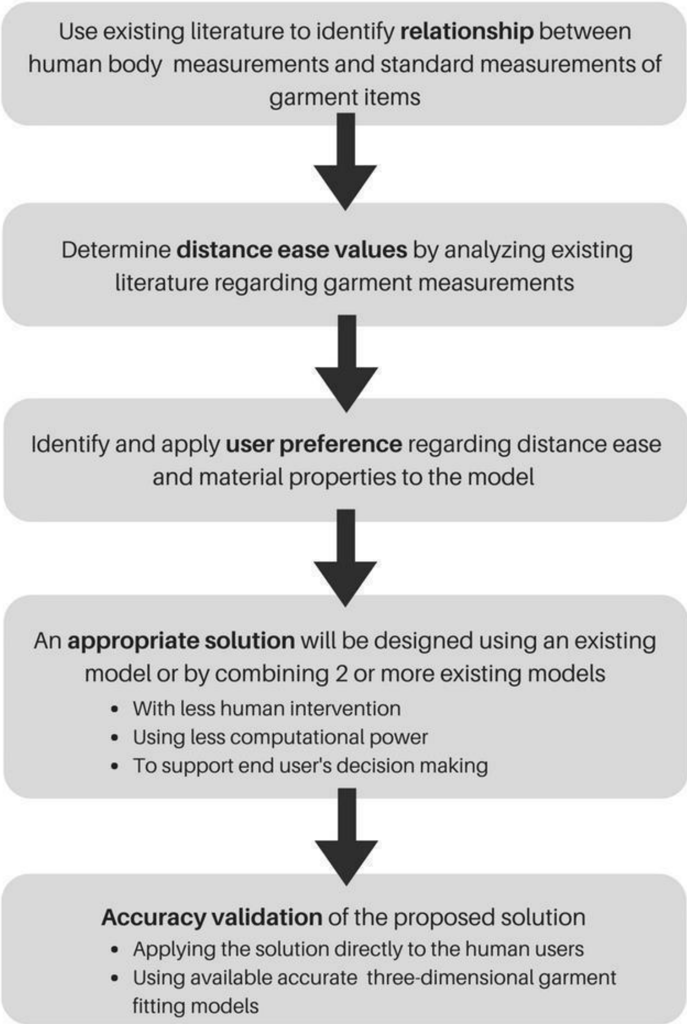


Figure 1.1. Research Approach

1.5 Goal

The goal of this study is to facilitate both buyers and retailers who can be considered as the two parties participating in an online apparel transaction. Through this research we are trying to enhance the confidence of the buyers when purchasing apparels online and facilitate them with time saving shopping experience. Furthermore it is intended to facilitate retailers with increased return on investment and support them to experience a decreased rates of returns.

1.6 Objectives

- To create an online garment fitting application with less user intervention and less computational power to provide a representation of the fit of garments utilizing a short period of time in order to support shopper's decision making
- To identify the relationship between human body measurements, and measurements of garment items
- To determine how user preference and distance ease can be incorporated to the fitting model and final output

1.7 Delimitation

In this research study, we mainly considered about the returning issue of online purchased garment items due to the size mismatches. The research study was conducted for the grownup males using shirts. The issue of size mismatches was taken into consideration and other reasons for returning such as quality issues and damages were not considered in our study. Further, the garments with complex patterns and designs in terms of measurements were not considered. Additional measurements of garment items were taken in addition to standard garment measurements when identifying the relationship with the human body measurements. User preference was taken as an input apart from the other human body measurements to determine the distance ease for the fitting model. As the final stage, with the intention of supporting the end user's decision making, a web based visualized solution was provided which will require less human intervention and low computational power.

1.8 Outline of the Thesis

The dissertation contains six chapters, structured as follows. The first chapter of the dissertation (Chapter 01) provides a general introduction to research. It discusses the motivation of the research highlighting the return rates of online purchased garment items. In addition, it provides an overview to the goals and objectives, research approach and delimitation of the research. Each section in this chapter should be read sequentially since they are chronologically ordered with respect to the primary concepts of the research. Preferably, this chapter should be read before the other chapters of the report.

The second chapter (Chapter 02) describes the relevant background studies in detail and their applicability and the drawbacks considering the online market place. This chapter includes different topics and concepts that come under the field of virtual garment fitting. Various technologies used in the industry, different findings of the research community and the evolution of these concepts are analyzed and presented in this chapter.

The third chapter (Chapter 03) describes in detail the research paradigmatic framework within which the research has been conducted and the justification of our selection has been clearly stated. Further, the methodology of conducting the research based on the methods that are common and valid within the identified research paradigm and design of the research has been discussed in this chapter.

The fourth chapter (Chapter 04) describes in detail the implementation details of the prototype system based on the proposed research design. It describes the mathematical aspects of the system by providing related equations where necessary. Further, it outlines the interfaces and functionalities of the developed research prototype. Finally, the chapter highlights the solution provided for the third research question through implementing the research prototype.

The fifth chapter (Chapter 05) describes in detail the results of the research subject to the implemented research prototype. Further, the chapter presents the qualitative evaluation of the results based on two approaches, in order to make a sound validation to proposed research design and implemented research prototype. This chapter also compares the accuracy of the implemented prototype with the accuracy of commercially available software applications.

The sixth chapter (Chapter 06), the final chapter of the dissertation, describes the discussion, conclusion and future works of the research. In the discussion, the contentious areas of the research results are discussed with the appropriate directions to answer those problematic questions. Further, the chapter presents the conclusion of the research emphasizing and highlighting the requirement for the research and the value of the research with respect to the human kind. Moreover it describes in detail the contributions made towards the growth of research community and future enhancements which can be performed with the ultimate intention of serving the human kind.

Chapter 2

Background

This chapter elucidates some of the main concepts of online virtual garment fitting applications and latest technologies used in the clothing industry via elaborating the work done by various research studies with reference to the concepts identified. This chapter also includes comparisons of the methods applied in the related research studies.

2.1 Usage of Anthropometry in Clothing Industry

According to Pheasant and Haslegrave (2006) anthropometry is a branch of human science which deals with the measurements of the human body in terms of size, shape, mobility, flexibility and working capacity [11]. It is observable that human body dimensions and proportions vary from one to another which triggers the necessity of understanding and analyzing the variances of the human body dimensions as well as the relationship among those.

Modern anthropometry involves a variety of measurements, and each study area utilize different sets of measurements according to its relevance. When describing the dimensions of human body, there are six main measurements that could be taken into account as shown in Table 2.1.

Table 2.1. The basic anthropometry measurements

Height	Point-to-point vertical measurement
Breadth	Point-to-point horizontal measurement running across the body or segment
Depth	Point-to-point horizontal measurement running fore-and-aft along the body
Curvature	Point-to-point measurement following a contour
Circumference	Closed measurement that follows a body contour
Reach	Point-to-point measurement following the long axis of the arm or leg

These measurements can be extracted accurately only when the subject is positioned in previously established postures. Pheasant and Haslegrave (2006) have presented correct standing and sitting postures (Figure 2.1) in which the extraction of human body measurements could be obtained more accurately.

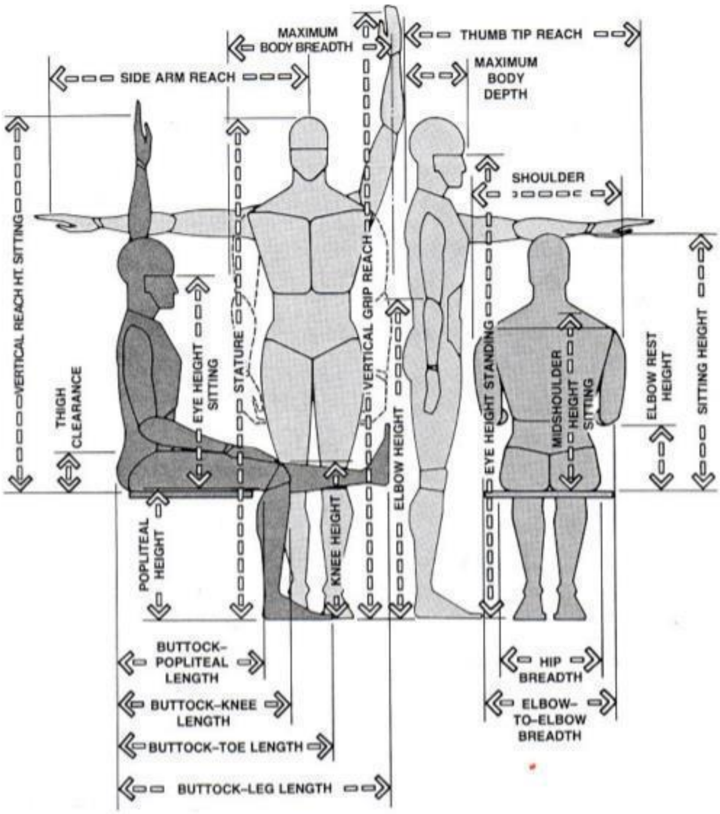


Figure 2.1. Standing and Seated postures for extraction of anthropometry measurement [11]

Customized cloth making has become a very time consuming and costly process as the cloth production for general public has become a trend in the era of industrialization. The inception of massive cloth production for the general public has triggered the standardization of clothing sizes according to a clothing pattern grading system that was introduced by the experts in fashion industry. The standardization of cloth sizes was established by considering the spectrum of body ratios and shapes of general public, and grouping those with close body dimensions into each category. According to Schofield and LaBat (2005), the aforementioned pattern grading method presents a standard way of making adjustments (either larger or smaller) to cloth design patterns with reference to the predefined set of human body sizes [12]. This pattern grading system has a strong correlation with anthropometry.

According to Huang (2012), the apparel industry uses ASTM D5219-09 and ISO 8559:1989 standards for taking anthropometric measurements and locating anatomical landmarks on human bodies [13]. These standards are used to locate body features on the parametric human models for which 3D garment should align with. Figure 2.2 visualizes these body features (Waist line (WL), Bust point (BP), Bust line (BL), Hip line (HL), High hip line (HHL), Center front (CF), Center back (CB), Front neck point (FNP), Side neck point (SNP), Back neck point (BNP), Shoulder point (SP), Chest line (CL), Front arm point (FAP), Back arm point (BAP), Lowest armhole point (LAP, Side seam (SS), Princess line (PL), Front side seam (FSS) and Back side seam (BSS)).

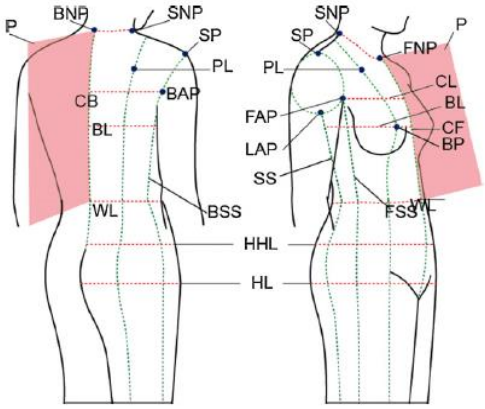


Figure 2.2. Anthropometric body features [13]

Apart from the aforementioned standard measurements, there are eight body measurements required to be obtained for a normal trouser according to Chen (2008), and these parameters can be classified into two classes as follows: (1) Vertical type. Waist to hip, out leg, curved front body rise. (2) Girth type. Thigh girth, waist girth, half back waist, hip size, half back hip [14]. Figure 2.3 clearly shows these eight body measurements required to be obtained for a normal trouser,

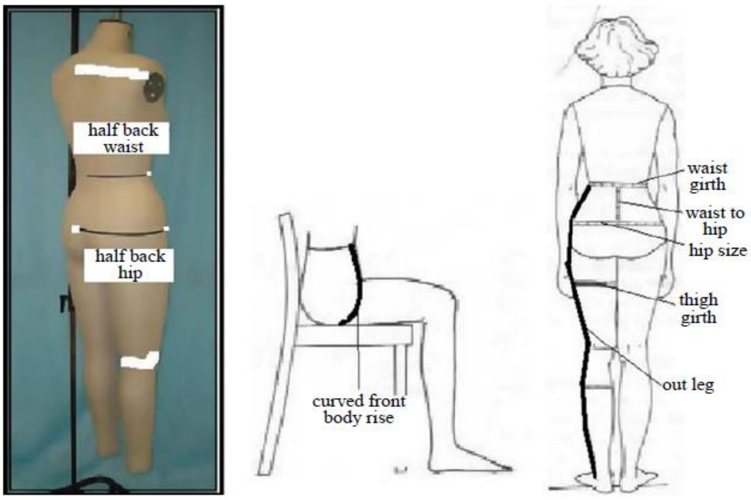


Figure 2.3. Relevant body measurements related to the gluteal region and the trouser of normal size [14]

Hence, study of anthropometry is with high importance for apparel industry in order to carry out mass cloth production for general public, as the major obstacle in this field is producing clothes that fulfil the fit requirement of each shopper.

2.2 Avatar Generation for Virtual Garment Fitting

This section will be focusing on the generation of avatars that represents human body in various virtual fitting applications. Avatars are commonly used in web based applications, and some common utilizations of avatars will be discussed in this chapter. Human body measurements are considered as one of the main inputs which can be entered manually to generate an avatar. Apart from the human body measurements, the shape of the human body can also be extracted from numerous measuring and capturing technologies such as laser scanning, multi-camera capturing, motion detection and etc.

2.2.1 Use of Generic body models

One popular method of representing virtual human body construction and animation is the usage of generic models [15]. There, the creation of face, body skeleton and body surface have been considered using the generic models. This avatar generation approach starts from default virtual human templates that includes shape and animation structures. Then the shape will be modified to create a new virtual body model.

As one way, photographs have been used as inputs, where front and side views of the face and front, side and back views of the body were taken. This method is a feature-based modelling of bodies which could be animated. With the generic human models, they have modified the shape and skin colour is adapted with given photographs. After that, the shape modifications are transmitted to the attached animation structures and as an output of this modelling process “ready to animate” virtual human is acquired. For the generic body animation, they have used a walking motion that obtained from a motion capture system which uses six cameras with sample rate of 120Hz along with 25mm markers. Following several steps the generic model is animated with skin deformation. Then a generic body is gained with seamless surface and real-time skin deformation capability whenever skeleton joints are animated with given animation parameters.

In another way, certain measurements of human body have been used to adjust the generic models to generate the avatar. There, they have taken eight length measurements that has to be entered by the user and based on that particular segments of avatar are adapted and others are done using interpolations. Those measurements are as follows in Table 2.2.

Table 2.2. Eight basic measurements to form an avatar [16]

Body Measurement	**Definition**
Stature	Vertical distance between the crown of the head and the ground
Crotch length	Vertical distance between the crotch level at centre of body and the ground
Arm length	The distance from the armpit and shoulder line intersection over the elbow to the far end of the prominent wrist bone in line with the small finger
Neck girth	The girth of the neck base
Chest/bust girth	Maximum circumference of the trunk measured at bust/chest height
Under bust girth	Horizontal girth of the body immediately below the breasts
Waist girth	Horizontal girth at waist height
Hip girth	Horizontal girth of the trunk measured at hip height

In addition to that avatar generation has been done using the generic body models in another research [17]. There, they have created immediate animatable human body model by doing the modifications to an existing reference model which was done by University of Geneva. They have created the generic human body models for standard five types of sizes (Extra Small, Small, Medium, Large and Extra-large) for each gender. How they have done that was, the reference generic model sliced into set of outlined shapes and each of these shapes are corresponding to set of measurements. According to the specified sizes, outlines were bent to fit the corresponding measurements and then bent the mesh to interpolate the bent outlines to generate a body shape in the model. Table 2.3 shows the primary measurements that they have used to complete the generic female body model.

Table 2.3. Primary measurements used to generate female human body model [17]

	Female standard body sizes	**XS/34**	**S/36**	**M/38**	**L/40**	**XL/42**
Primary Measurements						
1	Height	168	168	168	168	168
2	Bust Girth	80	84	88	92	96
3	Under Bust Girth	71	74	77	80	84

4	Waist Girth	65	68	72	76	80
5	Hip Girth	90	94	97	100	103
6	Inside Leg Length	78.3	78.3	78.1	77.9	77.7
7	Arm Length	59.6	59.8	60	60.2	60.4
8	Neck Base Girth	34.8	35.4	36	36.6	37.2

2.2.2 Use of Laser Scanning

The creation of 3D avatar can also be done using laser scanning [18]. Here, customers who needs to try on clothes are captured at the beginning. The customers have to visit the store to accomplish this scanning and there by using a 3D laser scanner customers body surface will be scanned within a few seconds and produces a 3D point cloud consisting of round about 450.000 to 600.000 points. Then a mesh is generated (Figure 2.4) out of these scanned point clouds and textures and acts as the basis for the virtual avatar. By applying skin deformation methods to this created basis of virtual avatar which is based on the combination of vertex-blending and bone-bending, the finalized avatar is capable of generating simple animations as well.

Figure 2.4. Different stages creating an individual customer avatar: Scanning the customer's body surface (left). Static avatar (middle). Dynamic avatar (right) [18]

2.2.3 Use of Optical Tracking

The application proposed by the paper "Free Viewpoint Virtual Try-On with Commodity Depth Cameras" uses optical tracking in order to scan a person, and use the scanned body mesh as an avatar later [19]. The suggested application use a multi-camera setup with ten cameras, resolution of 640x480 to capture a person in all sides to get his/her body measurements. To keep separately each individual's image, the coloured background is used. This method is used for its fast process of scanning comparing to the other methods. Here, a mesh that represents a human body is adjusted (Figure 2.5) as the pose of the mesh is adapted to the pose of the scanned person. Then the OpenNI [20], pose estimation algorithms are used to convert the image into a depth map. By using deformations and based on the images, the mesh is matched in order to resemble the proportions of the captured person which can be shown in figure 2.5 illustrated from [19].

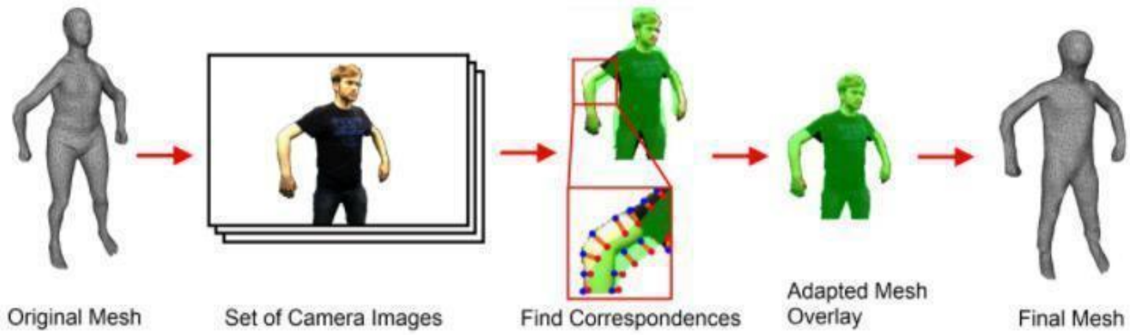


Figure 2.5. The figure shows the transformations that are applied on the original mesh based on the multiple camera images [19]

Apart from that, if a person was not scanned yet, there is a possibility of importing an avatar with self-determined measurements. Here, the avatar can be generated using an application that is designed for the creation of human bodies.

In 2015 Dong-Eun Kim and Karen LaBat have examined the consumer experience and satisfaction in using 3D virtual garment simulation technology for online shopping and consumers' willingness to use the technology [21]. Through this research they have identified that consumers do not prefer 3D virtual garment simulation technology for online shopping due to privacy issues of revealing their body dimensions and consumers faced discomfort of viewing their own body scan. Even though they thought that this would be a good starting point for judging fit, consumers did not had much positive attitude in using 3D virtual garment simulation technology.

Table 2.4 displays a comparison of related studies based on the approaches they have applied to generate avatar models. This comparison also includes the approach applied by the current research study in order to highlight the difference between related studies.

Table 2.4. Overview of utilizing generic body models, 3D laser scanning and optical tracking with commodity depth cameras for virtual garment fitting comparing with 2D body model

	Use of Generic body models			Use of 3D Laser Scanning	Use of Optical Tracking with commodity depth cameras	Use of 2D patterns of human body model
	Use photographs as Inputs	Use human body measurements	Use default virtual human templates			
Cordier et al. 2001	✓					
D. Protopsaltou et al. 2002		✓	✓			
A. Divivier et al. 2014				✓		
S. Hauswiesner et al. 2011					✓	
Proposed solution		✓				✓

Though there are different ways of generating an avatar, most of these are unable to use in real-time applications as it requires huge computational power. As a result, there is a need of an avatar generation method which requires low computational power that can be used in online marketplace.

2.3 Real-time Garment Fitting Technologies for Virtual Garment Fitting

This section presents current virtual fitting technologies applied in related studies used to track human body shape and movements. These technologies can be categorized into two; marker-based technologies and markerless technologies. Marker-based approach uses different techniques. Fiducial markers and optical markers are such techniques that come under this approach. Depth camera technique is known as a sophisticated markerless technology which enables motion capturing and full body depth detection. The introduction of rendering and calculating both the structure of skeleton and corresponding joint positions from depth cameras the superimposing and animating of the garment is enabled.

This section presents a detailed description regarding the application of fiducial markers and depth camera in the field of virtual garment fitting, followed by a summarized view of the real-time tracking technologies used by related studies for virtual garment fitting.

2.3.1 Markers

Marker-based approach can be used as one of the methods to track the shape of the body by placing these markers on predefined positions of the surface of the body. These are known as fiducial markers since the placement of the markers are done in accordance to the comparison of the placements of other markers. In virtual fitting trials these markers are identified in real-time with the usage of image processing techniques based software after analysing images captured by specific video cameras; specially calibrated cameras.

In a study that presented an Augmented Reality application called ARDressCode has applied the concept of markers for their study [22]. Three cameras have been setup to capture the shopper's body, and with the usage of Augmented Reality Toolkit, the images captured by the camera are analysed in order to place a set of predefined markers. As the final step, the 3D model of the garment is positioned on the body considering the markers (Figure 2.6).

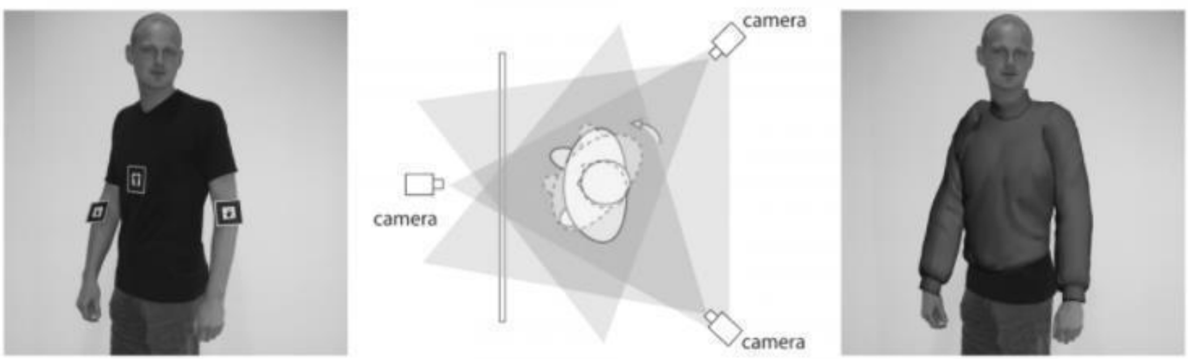


Figure 2.6. (Left) Positions of fiducial markers, (Middle) Three cameras pointed to the shopper to capture from all sides, (Right) Cloth positioned on the body based on markers [22]

In another study done in 2008 [23], the researchers have applied markers on the joints of the user using an algorithm that detects accurate positions of the body. Finally a 2D garment is positioned on the body of the user based on the markers. The cloth is provided with triangle vertex information to transform the 2D garment into a more realistic garment in order to provide realistic behaviour to the garment when animating it.

With the introduction of markerless tracking system it was identified that marker-based approach is an error-prone method as the real-time positioning of the markers were less accurate. The following subsection discusses such technology that is able to identify the human body shape without placing markers all over the body.

2.3.2 Depth Cameras

In a study done in Japan, 3D body shapes of the participants were obtained using depth cameras in order to in order to overlay the clothing images that is with similar body shape [24]. The subjects are captured with depth cameras, resulting single-shot depth images. This single-shot depth image is used to obtain the 3D body model of the subject with the application of depth data. Clothing images were obtained from 50 subjects representing different body shapes, and a clothing database was created including 2D clothing images and its corresponding body shape manifolds. Once the single-shot depth image is rendered, the shape of the body model is estimated using depth data. Finally the most suitable clothing image with similar shape is selected from the clothing database. This 2D clothing image is transformed and overlaid on the body model in real-time. Figure 2.7 shows the aforementioned process. This method was able to produce more accurate garment fitting for the users, but with the high cost of large databases and equipment, the usage of depth cameras is inappropriate for an online marketplace.

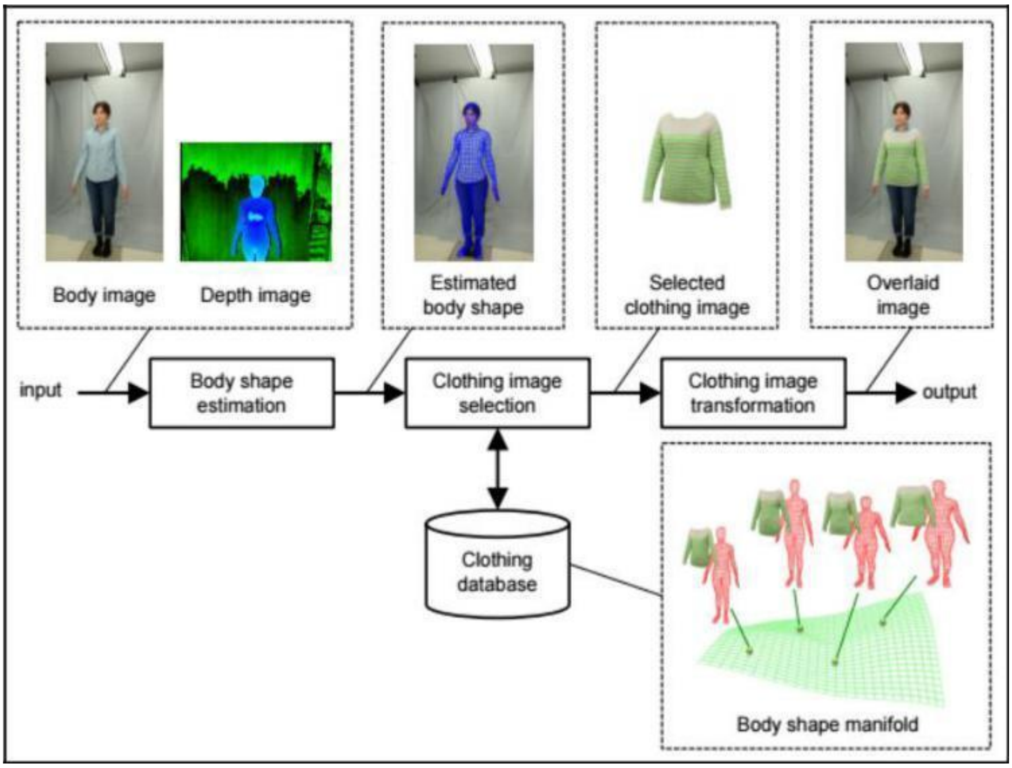


Figure 2.7. Process flow of the study done using depth cameras

Table 2.5 contains a set of real-time tracking technologies used for virtual garment fitting. It compares the usage of real-time tracking technology for virtual garment fitting in different related studies. The method proposed by the current study for virtual garment fitting is also included to this comparison

Table 2.5. Overview of the use of real-time tracking technologies for virtual garment fitting

	Use Markers		Use Depth Cameras/ Depth Images	Capture Shopper's Body	3D Model of The Garment	2D Image of Garment	2D pattern of the garment - reverse process
	Predefined Markers	Markers on Joints					
ARDress Code	✓			✓	✓		
Follow-the-Trial-Fitter		✓		✓		✓	
M. Sekine et al. (2014)			✓	✓		✓	
Proposed solution							✓

2.4 Virtual Cloth Generation and Simulation

Generation and simulation of virtual cloth can be done in various ways such as creating a 3D mesh to represent cloth, scanning an existing cloth using laser scanning techniques or using 2D planes with considering the texture of the fabric.

From a research done in Graz University of Technology [19], they have generated the garment items virtually based on a multi-camera setup. With the assistance of this set up, a person will be captured who is wearing the actual cloth and the cloth should be separated from the body which can be done both manually or using Chroma key technique. When it is trying, the size has to be deformed in order to match the measurements of the person. For this they have applied physics on the clothes by using PhysX engine of Nvidia to check the collision with body parts and this simulation using physics are mainly used for garment items like skirts.

In another method which is used for cloth generation [15] [16], described in two research papers which was published in 2001 and 2003 respectively, first the outline of the cloth is drawn and placed on the body. After completing series of steps, finally the garment is adapted automatically according to the shape of the model. When simulating the cloth to the human body, the garment is differently treated with respect to the position of the body as shown in Figure 2.8.

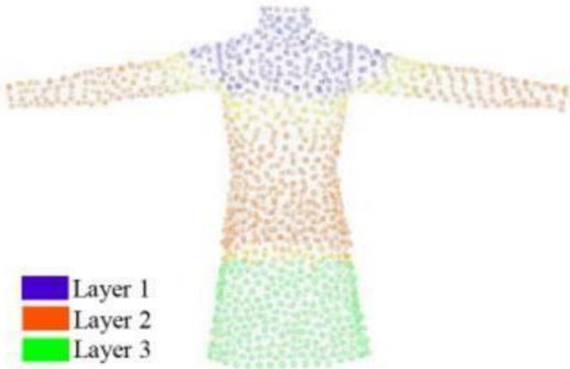


Figure 2.8. Different layers (represented as vertices) of garment. The cloth is simulated differently in respect to the particular position of the garment on the body [16]

With a different technique that provides a realistic visualization of clothes is presented in a research [18] it have been mentioned that a finished results of cloth generation and simulation should give the real feeling of material properties to the users. In this method, clothes are created using 2D CAD geometry models and these models are typically utilized in the fashion industry. Apart from that, these CAD files provide the information about how to sew the garment item which can be used to position the particular parts of the cloth around the avatar considering certain points of the human body. After that, virtual sewing can be conducted in accordance with bounding surfaces and to complete this cloth animation and physics are utilized. There, to get the realistic behaviour of the garment functions called Bidirectional Texture Functions (BTF) are introduced. This function consists of several images of textures that are taken from various viewing angles. Moreover, for an automatic measurement of garment consist of a light and movable camera on a rail system is important which is needed to capture garment item from different viewing angles. With that, many particular properties like anisotropic reflection properties, subsurface light transport, interreflections, self-shadowing [18] of material can also be recorded. Figure 2.9 which is extracted from [18] shows the difference between BTF and normal texture mapping. This figure on the left illustrates the capturing setup when using BTF. The camera is moved on a rail to caption the sample from all directions. The image on the right side shows the significant difference between a rendered simple texture (left) and a BTF (right). As described in the paper, it delivers some important aspects of cloth generation that should be considered in the creation process of virtual fitting room as well.

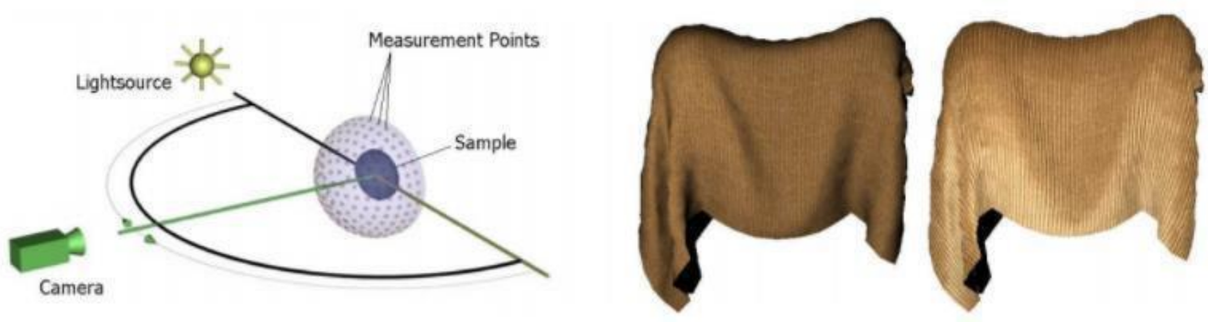


Figure 2.9. (Left) The capturing setup when using BTF (Right) The significant difference between a rendered simple texture and a BTF [18]

Another research which was conducted in University of Geneva [17], they have used 3D garment simulator namely MIRACloth that was developed in University of Geneva. It includes modules such as mechanical model, collision engine, rendering as well as animation. Moreover a plugin, 3DStudio Max has been used for the integration part of the algorithms as well. In this research they have conducted the cloth simulation in two stages, garment assembly stage and garment animation stage. Here, garments are designed using the traditional 2D pattern approach and these patterns were created using Modaris software package. The created 2D patterns were placed around the body and with the mechanical simulation, the patterns were forced to attached and seamed on the borders to attain the shape. In the first step, optimization of seaming speech is only considered and have not focused in giving exact fabric behaviour. Then in the second step, with the defined mechanical parameters, it is set to give actual fabric behaviour and finally accomplished of giving the animation of the garment on the virtual body. The process of this method can be seen in figure 2.10, extracted from [17].

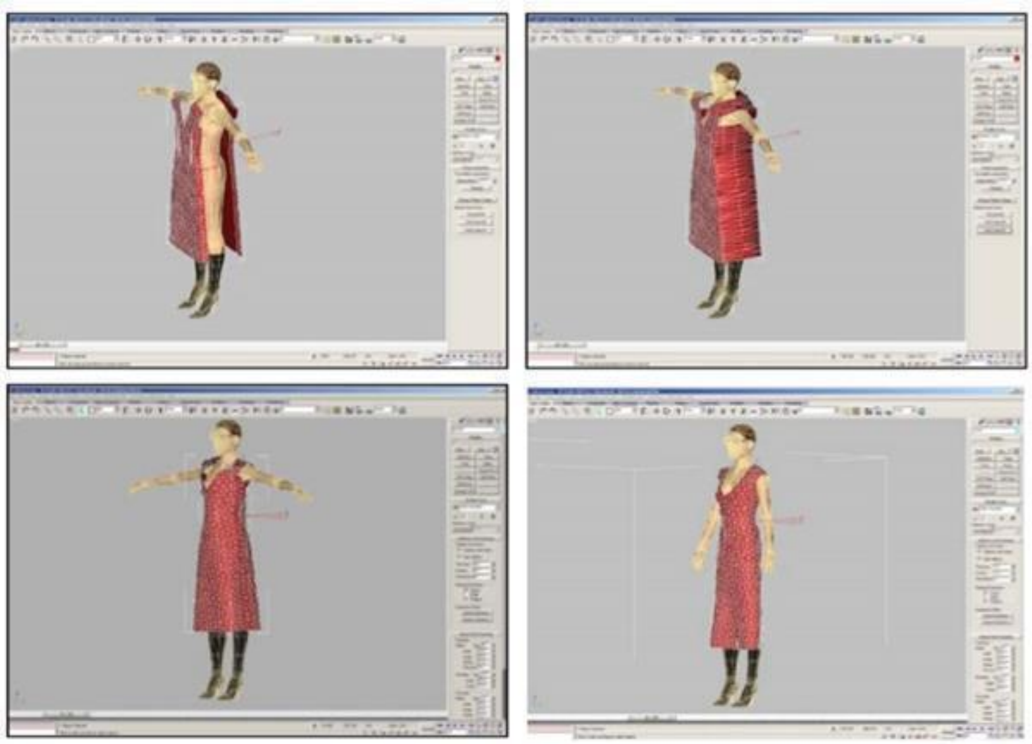


Figure 2.10. 3D simulation of cloth [17]

2.5 Virtual Clothing in Computer Graphics

Virtual clothing supports the reproduction of physical behaviors and the visual features of textile objects in computer simulated virtual reality [25]. Virtual clothing can be classified into three main categories such as geometrical based, physical based and hybrid virtual clothing methods. Distinction among these categories are identified based on the core technique used for formulating shape of the cloth or for driving its deformation.

2.5.1 Geometrical Based Virtual Clothing Methods

These techniques mainly concentrate on the properties related to appearance particularly folds and wrinkles which can be represented by geometrical equations. Physical properties of cloth will not be examined through these methods. Geometrical based virtual clothing methods require a substantial amount of user intervention which can be considered as one of its limitations.

The roots of geometrical virtual clothing methods spread back into 1986. Weil (1986) was able to introduce a way of modelling for 3D hanging cloth material [26]. Catenary curves between hanging points of cloth were used to induce shape of the cloth. This method can be used only to generate the hanging cloth and it cannot be used to generate a more complex cloth shape. T. Agui and Nakajima (1990) presented a way of modelling a sleeve on a bent arm [27]. According to their observation, consequence of differences in curvature between inner and outer part of the sleeve has caused formation of folds. This method focuses mainly the simulation of bent sleeve. Hinds and McCartney (1990) aimed at automation of manufacturing garments [28]. In this method upper body of a mannequin was digitized to obtain shape of human body and numerous three dimensional (3D) panels were used to represent a garment. Afterwards Hinds et al. (1991) proposed a way of translating three dimensional(3D) panels into two dimensional (2D) patterns using method of Calladine (1986) [29] [30]. Miller et al. (1991) proposed a new approach to the issue of producing a simple topologically-closed geometric model from a point-sampled volume data set [31]. A simple geometry as an initial topologically closed object such as a sphere or a cube was proposed through their research. Then the process of expanding this simple object in order to fit the object within a volume has been conducted. An extension of this method into cloth modelling was proposed by Thomas Stumpp (2008) [32]. Linear time complexity was reached considering number of mesh vertices through their method. Physical property of cloth can be affected by the topology of cloth mesh as physical property of the cloth is correlated to the size of clusters. Decaudin et al. (2006) introduced a method to create visually realistic clothes by wrapping developable surfaces around the character body in a natural manner [33]. The sewing patterns from 3D cloth model was provided by flattening the developable surfaces. A three dimensional (3D) surfaces were generated around character body using a sketch based interface and manually added the seam lines on these surfaces directly. A feature based method for the construction of 3D cloth from 2D sketches was proposed by Wang et al. (2003) by considering predefined human body features as base [34]. Tailoring rules in fashion industry were used to define features of human body based on the profiles of different body parts. 3D cloth templates are pre-constructed considering each type of cloth. This method can generate only simple cloth meshes which needed to be processed further to complete a detailed cloth. An interactive way for putting and manipulating clothes on a 3D model was introduced by Igarashi & Hughes (2002) [35]. 2D patterns are used to generate 3D cloth in this method and this can be used to model simple style cloth without foldings and also because of the computational cost cloth-cloth collision is disregarded while calculating surface constraints of 3D cloth mesh. An approach for designing 3D cloth directly on a 3D mannequin model was introduced by Wang et al. (2009) considering constrained contour curves and style curves [36]. To define general shape of clothes, contour curves such as silhouette curves and cross section curves were used whereas to generate detailed 2D cloth patterns on cloth surfaces style curves such as seam lines, notch lines and dart lines were used. This approach can be considered as an intuitive and appropriate way of designing complex cloth on a 3D mannequin. Further knowledge in fashion design and patternmaking is required to edit contour curves and style curves. Flexible shape control method was proposed Meng et al. (2012) for resizing 3D garments automatically while preserving shape of user-defined features on clothes [37]. Any kind of cloth modelling techniques can be used to generate 3D clothes are modelled on a reference human body. Safeguarding of cloth features can be highly influenced by inconsistent user inputs since feature curves are defined by users based on each cloth modelled for target human bodies. An automatic way of cloth transferring between characters with different body shapes was introduced by Brouet et al. (2012) [38]. Vertices are adjusted on 3D cloth in order to fit a cloth onto a different character and pattern extraction will be happened after fitting 3D cloth to a new character through this method. Sketch based interface for modelling 3D cloth on virtual characters was proposed by Turquin et al. (2007) to model cloth on a 3D character based on stocks drawn by users [39]. This method can only be used to model simple style single layer clothes since information from user input stroke cannot be used to define complex cloth structure. An interactive tool was introduced by Umetani et al. (2011) for cloth design that enables bidirectional editing between 2D patterns and 3D cloth [40]. Real time physics-based simulation method is used to simultaneously update the topology of 2D cloth pattern and its corresponding 3D cloth piece by user input, in order to maintain synchronization between 2D and 3D. The method proposed through this method cannot be used for simulation of cloth dynamic behaviour subject to motion of 3D character as synchronization of 2D pattern with a 3D cloth on a static 3D mannequin cannot be performed through this method.

2.5.2 Physical Based Virtual Clothing Methods

Triangular or rectangular grids with points of fixed mass at intersections are used to represent cloth models in this physical based virtual clothing methods. Two types of models such as energy-based method (Terzopoulos et al. 1987) and force-based method (Volino and Magnenat-Thalmann 2005) can be recognized in physical based virtual clothing methods [41] [42]. Total energy of cloth is calculated using some equations in energy-based model. The shape of cloth is derived using these equations by moving points to achieve minimum energy state. In force-based models, forces among each point are represented as differential equations. Position of points at each time step are obtained by solving these differential equations using numerical integration. A method for the construction of shape of a cloth object has been proposed by Terzopoulos et al. (1987) [41]. Shape and motion of deformable materials has been described using elasticity theory in this approach. Simulation of dynamic behaviour of objects can be implemented by fetching physical properties such as mass and damping in to physical simulation. General mechanical model for cloth simulation was introduced by Volino and Magnenat-Thalmann (2005) for cloth simulation [42]. Instead of mass-spring system, an accurate particle system for dynamic simulation is presented through this model. Three 2D coordinates have designed considering three mechanical properties such as weft, warp elongation and shear and these were used to describe a triangle face of cloth mesh. A simulation model for large deformations of textile was proposed by Volino et al. (2009) [43]. Simulation process has become simple through this model and it enables creation of nonlinear tensile behaviour of textile with accuracy and robustness. An approach to simulate inextensible cloth in a collision-free condition subjected to a conservative force such as gravity was proposed by Chen and Tang (2010) [44]. Stretch resistance and compression resistance of a cloth is greater than its bending resistance according to this paper. Transformation of deformation process of an initial developable mesh surface to a final mesh surface through physical based simulation process has been proposed via this method.

In general physical based virtual clothing methods are used to produce behaviour of flexible object that resembles cloth. Rate of resemblance will vary based on used physical based virtual clothing technique.

2.5.3 Hybrid Virtual Clothing Methods

Hybrid virtual clothing methods have been developed by combining both geometrical based virtual clothing methods and physical based virtual clothing methods to compensate deficiencies in those methods to deliver a proper solution. Rudomin (1990) proposed a method to diminish the computational complexity of physical based virtual clothing methods [45]. He presented a mechanism which can be used to lower computational time of physical based virtual clothing method which was introduced by Terzopoulos et al. (1987) [41]. After a while a series of hybrid virtual clothing methods were proposed by Kunii and Gotoda (1990) [46]; Tsopelas (1991) [47]. Geometrically modelled fine wrinkle details were mapped onto a physically simulated cloth mesh using these methods.Texture based wrinkle modelling method was introduced by Hadap et al. (1999) for cloth simulation [48]. Deformation details will be generated through this method by considering basis as bump map which will be created by user on a physically simulated bristly cloth object. Kinematic method for generating wrinkles on cloth for computer generated (CG) characters was proposed by Cutler et al. (2005) [49]. Through this method they were able to find out that these similarities could be revealed only on tight fit cloth. Due to that it was impossible to generate shape detail on loose fit cloth using wrinkle database. A method to generate fine detailed folds on captured cloth model was proposed by Popa et al. (2009) [50]. Shape and position of wrinkles were captured from video footage through this method by considering basis as the distinguishing shape characteristics of wrinkle. Feng et al. (2010) introduced a method to provide high quality dynamic folds and wrinkle for cloth simulation by maintaining real time ability [51]. Geometrical based virtual clothing method was used to capture relationship between two different resolutions of mesh and transformation process was executed using this relationship. They developed an animation production pipeline which always starts with physical simulation of low-resolution mesh. Through this method they have evaluated collisions between each proxy bone instead of calculating collision between each mesh triangles of cloth and body model, when a character moves. Computational time taken to calculate collisions has reduced considerably even though there is a slight reduction in the accuracy of collision handling. Researchers have been succeeded in improving the efficiency, but a pre-simulation is required to obtain training data and it will be a time consuming process.

2.6 Ease Allowance and Distance Ease Distribution

Ease has become a crucial feature in clothing industry in order to deliver appropriate garment fit to the wearer. Many researchers have identified a variety of factors that are having a considerable relation to the ease allowance of a garment block pattern construction. Rasband and Liechty (2006) have explained that design style, fabric physical and mechanical attributes, body shape, wearing occasion and personal preference are the main factors that impact the amount of ease needed [52]. Chen, Zeng, Happiette and Bruniaux (2008) have categorized the factors related to ease allowance into three; standard ease, dynamic ease and fabric ease [14]. According to Gill (2011), there are five contributing factors that determine the ease of a garment pattern such as Function, Comfort, Oversize, Fabric and Styling [53]. Huang, Mok, Kwok, & Au (2012) has identified the amount of clothing ease depends on the design, fabric used, functions of a garment, and even personal preference of customer [13]. Based on these, two type of eases were identified; wearing ease and design ease. As it can be seen, almost all the researchers have considered the shape of the human body and fabric properties to determine ease allowance [13] [14] [52] [53], and these have been identified for having a strong and direct relationship with the distance ease distribution between body and garment [54] [55]. Some of the researchers have identified that other than the body shape and fabric properties, the design of the garment, personal preferences and body movements also have a significant impact on the amount of ease allowance required. Still, there are questions left unanswered for the identification of the relationship between these factors and distance ease distribution when a garment is draped upon a human body. Table 2.6 shows the comparison of different factors considered by related studies that affect the distance ease values.

Table 2.6. Factors affecting the distance ease

	Design Style	Mechanical Properties of a garment	Functions of a garment	Personal Preference of comfort	Body Shape	Wearing Occasion
Rasband and Liechty (2006)	✓	✓		✓	✓	✓
Gill (2011)		✓	✓	✓		
Huang et al. (2012)	✓	✓	✓	✓		
Chen et al. (2008)		✓			✓	
Lage (2017)		✓				
Proposed solution	✓		✓	✓	✓	

Furthermore, many studies have used 3D body scanning data in order to evaluate the distance ease distribution [13] [14] [53] [54] [55] [56]. Xu (2008) and Lage (2017) have presented the impact on the distance ease between the body and garment by using a variety of fabrics, while uniformly changing the ease allowance [54] [55]. Both studies showed that the 3D distance eases at different body angles changed irregularly with the increase of garment sizes and the uniform changing of material mechanical properties, especially tensile strain (Figure 2.11(b) and (d)). Gill (2011) and Wang et al. (2006) have presented different mathematical models of ease distribution which plays an important role in the construction of basic garment patterns [53] [57]. Chen et al. (2008) have also presented a model to generate optimum ease allowance for the creation and manipulation of pattern construction [14]. Thomassey et al. (2013) have identified a template to determine ease in 3D patterns in order to generate personalized garment patterns [56]. With the identification of distance ease distribution among body and garment, Huang et al. (2012) have presented a model to flexibly distribute and accurately control ease in 3D patterns in order to convert those into two-dimensional [13]. 3D model of the garment is customized based on the distance ease values at each area of the body model (Figure 2.11(a) and (c)), and this customized 3D garment model is flattened and converted into its 2D pattern.

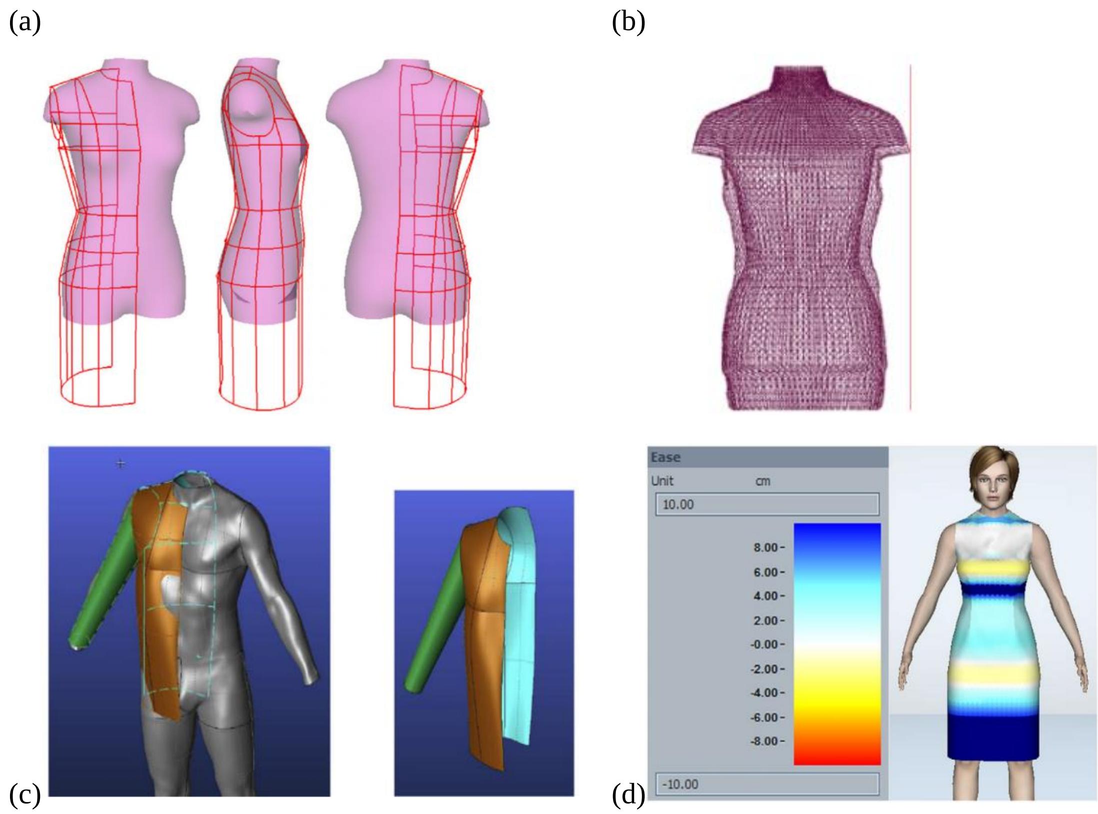


Figure 2.11. (a)The wireframe is established by distributing ease on the key positions and scaling the PBC model linearly [13], (b)3D scanning dressed mannequin [54], (c)Construction of the garment using 3D body models[56], (d)Distribution of distance ease in 3D virtual dress [55]

Furthermore, studies have been conducted to evaluate the distance ease distribution at bust section, waist section, abdomen section, hip section, thigh, knee and crotch curve using the respective cross-sections of the body. Moreover, dresses, long-sleeve tops, jackets, trousers have been used for the evaluation of distance ease distribution. There are still questions left unanswered for determining the garment fit for a given garment type without the usage of 3D technologies as well as for identifying the relationship between the distances ease distribution and wearer's personal fit preference.

2.7 Industrial Virtual Garment Fitting Applications

To solve the return rate problems and provide better fit, various technologies have been introduced and used by leading retail organizations**.** These technologies include 3D scanning, augmented reality, virtual reality and big data analysis. Several applications generate 3D models using two main approaches. One approach is 3D scanning which can be achieved with the use of scan booths available in retail shops. The other approach of generating 3D models is by the manipulation of the human body measurements that are the inputs of a user put into a computer. Then based on the garment size and the accurate human body measurements, the recommendations are given to the users with virtual try-ons. Other than these software applications which use 3D models to visualize the garment fit, many other applications have been introduced in order to depict the garment fit without the manipulation of 3D models. Big data has become a resource for such applications like Truefit where there are huge databases of user’s body sizes, preferences and purchase histories. The big data that consist in these huge databases will be analysed and provided with suitable recommendations [58].

Virtual reality and augmented reality are most promising technologies for a better fit that are used in today’s world in an increasing rate. The two technologies have been used for both online purchasing as well as in store purchasing. Following are some of the applications and technologies used in the fashion designing and apparel industry.

2.7.1 Bodymetrics

Figure 2.12. Bodymetrics application [59]

3D body scanning solutions for both home customers and retail stores have been designed by Bodymetrics which is a technology company located in London [59]. The aforementioned solutions are designed with the intention of serving the two groups of stakeholders participate in an apparel purchasing transaction.

3D full body scanning machine is designed for the retailers with the purpose of providing the exact body dimensions of customers. Therefore the sales of the retailers will be increased and they will experience a decreased rates of returns. Consumers will be able to gain a better shopping experience through this since the time taken to fit-on the clothes will be reduced considerably [60]. The mapping of customer's body will be done through eight PrimeSense 3D sensors in the retail version of the body scanner. It will facilitate fast and accurate calculation of 100 measurements which are used by "Fit Stylists" to find the apparels which suits best to the shape and size of the customer [61].

The online version of 3D body scanner is produced with the intention of serving customers when purchasing clothes from online retail stores. It will assist the customers to select the garments which matches with their shape and size without spending much time and with an increased confidence [60]. The aforementioned PrimeSense-based Natural Interaction (NI) sensors like Microsoft Kinect and ASUS Xtion has been used to create the online version of 3D body scanner. It will allow customers to scan their body and save body data to an online profile. An on-screen customer-sized avatar will be created using the aforementioned stored body data and avatar will follow the motions of the customer through the NI sensor. Further customers will be able to virtually try on garments and tight spots of the garment will be visualized using a colour map is overlaid on the garment [61].

2.7.2 Metail

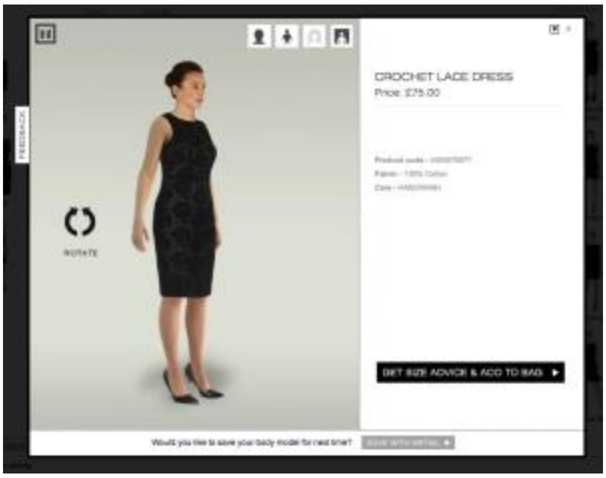


Figure 2.13. Metail application [62]

This application [62] has its own 3D visualisation technology in which the clothes shopper can upload a photo and input some basic body measurements. This will create a virtual representation of themselves, and the shoppers are able to try-on different garments virtually. The garments are professionally photographed and digitized depicting their material properties in order to provide a realistic appearance.

2.7.3 Rakuten Fits Me

Figure 2.14. FitsMe application [63]

This application manipulates robot mannequins according to the shopper's input body measurements, and visualizes selected garment items on the adjusted mannequins [63]. A limited number of body measurements were selected that are required to manipulate the mannequins via a deep statistical analysis of thousands of body scans. Data on weight, age and height are also incorporated into the solution when adjusting the mannequins.

Garments are visualized based on their material properties such as silhouette and stretch and the fit preference of the shopper. This application is able to provide size recommendations for the shoppers with the analysis of both body and garment measurements. Concepts in pattern making, fabric technology and designing are also used for the interpretation of cloth fit [64].

2.7.4 Webcam Social Shopper

This application can be used for online shopping sites and it allows users to use their webcam as a mirror to try apparel items virtually. Browsing can be done with the use of the wave of the hand/ hand movements and selected item will automatically adjust with the location that the user is. The application has the ability to change the colour of selected item and has motion capture interfaces which allows motion to snap photos and get other experience as well. The application provides the ability to share the photos in social networks and can be integrated within a day. For the users who try the application for the first time, they can use a free trial version to get comfortable with it. Moreover, it is a customizable application which is in 10 languages in the world as well as optimizable for in-store with new virtual dressing room technology called Virtual Style Sense (VSS) [65].

Table 2.7 contains a comparison between industrial applications with respect to different criteria. These industrial applications have been compared with the proposed approach of the current study.

Table 2.7. Analysis of virtual garment fitting applications

	Metail	Body metrics	Bodi.me	TrueFit	FitsMe	The Webcam Social Shopper (WSS)	Proposed solution
3D body scanning		✓	✓				
3D models	✓	✓					
Input measurements	✓		✓	✓	✓		✓
Size recommen -dations	✓	✓	✓	✓	✓	✓	
Virtual try-on	✓	✓				✓	
Big data				✓			
Use of 2D patterns							✓

2.7.5 Marvelous Designer

Marvelous designer is a 3D design tool which is used to design clothes and fabrics. It allows creating beautiful 3D virtual clothing with its cutting-edge design software while saving the designers' time. Marvelous Designer can virtually replicate fabric textures and physical properties to the last button, fold, and accessory. With its versatile compatibility with other 3D software and interactive design interface, users can instantaneously edit and drape garments onto 3D forms with high-fidelity simulation. Here, the technology is based on the art of sewing and patternmaking (making the blueprint for a garment), which is believed the only way to realistically express garments. Users don't need a fashion design background to create clothing using Marvelous Designer as it is surprisingly easy and simple with its intuitive tools [66]. The major drawback that can be found in Marvelous Designer is that it does not allow the user to either customize avatar sizes or edit avatar body measurements.

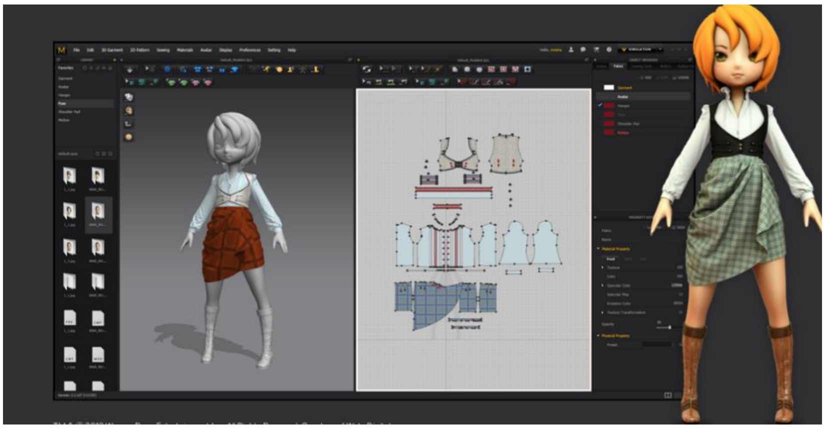


Figure 2.15. Marvelous Designer application [67]

2.7.6 CLO3D

CLO3D is also a 3D fashion design software application applied in fashion and apparel industries for the creation of realistic virtual garment visualization with highly advanced simulation technologies. CLO3D encompasses a feature for customizing avatar sizes by editing measurements of the avatars which is not available in Marvelous Designer. CLO3D delivers the most accurate and versatile 3D digital body shapes, in partnership with BodyLabs, a pioneer in generating true-to-life 3D body models [68]. CLO3D has the capability of transforming the avatar's body shape part by part. This transformation can be done according to the four body types that it consists of namely Slim tall, Heavy tall, Slim short and Heavy short. The changes of the four body types mainly based on the height and width of the avatar. Referring to the height of the avatar, the heel to the top of the head, disregarding the shoe's heel is taken and for width, the waist circumference measurement is taken as a standard. Adjusting the height depends on the avatar's main joints including "To Neck", "To Waist", "To Hip", and "To Knee" referring to the avatar's heel. Changes to the avatar's width, the circumference is taken from the "head", "hand" and "foot" areas despite of "waist" [69].

In spite of the fact that both Marvelous Designer and CLO3D share common technology behind its functions Marvelous Designer is primarily used in computer graphics, animations and gaming industries whereas CLO3D gives more robust solution in fashion and apparel industries with functions that can be applied to various stages of garment design development process and avatar generation process. CLO3D is not a "Marvelous Designer" version, it is simply a very smart way to cut time and save money when making production-line clothes for real humans. Changing Avatar sizes is only available in CLO3D and it allows for seems and a few other features for real life clothes.

As aforementioned, to make a 3D Avatar with exact specifications as a live human model the best is to use a 3D body scan which would be the most accurate way to get the exact specifications. But adjusting specific measurements of the default avatars is available in CLO3D software with its Avatar Editor (Figure 2.16). Except that, 3D body scans can be imported into CLO3D as long as they are in OBJ or FBX file format [68].

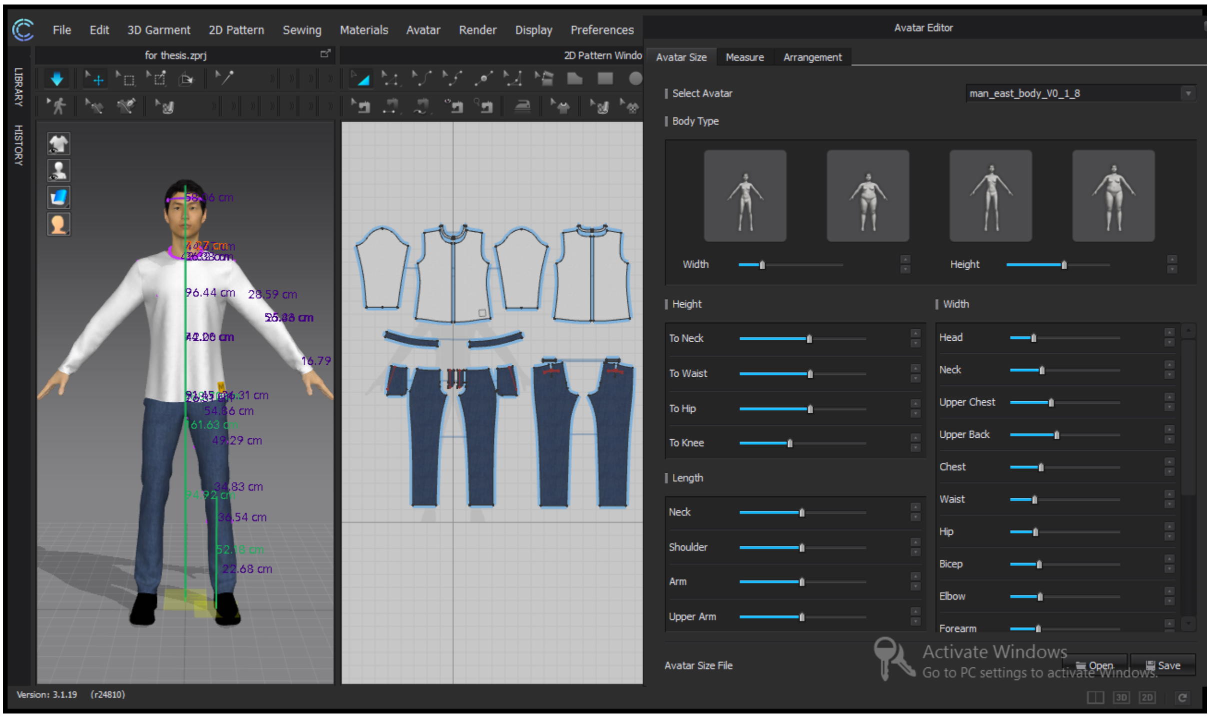


Figure 2.16. CLO3D Atelier Software

Including Marvelous Designer and CLO3D, there are several methods and tools currently available to check the fitness of a garment with human body. Most of these techniques demand high computational power since they deliver results utilizing available 3D technologies. Therefore time required for these applications to deliver results is relatively high and high user intervention is needed to deliver the solution. Further, users will access online marketplaces concurrently and it requires high speed delivery of results in order to control the network traffic. Thus, the applicability of aforementioned 3D applications to an online marketplace would be comparatively low. Therefore, there is a need for a lightweight solution which will support the decision making of the end user in order to select the properly fitted dress by considering human body properties and garment properties.

Chapter 3

Methodology and Design

3.1 Research Design

Our research has adopted the principles and guidelines of Design Science Research which seeks to create innovations that define the ideas, practices, technical capabilities and products through which the analysis, design, implementation and use of information systems can be accomplished effectively and efficiently [70]. Adoption of design science research paradigm has been transpired based on two divergent grounds. Firstly, design science research attempts to focus human creativity into the design and construction of artifacts that have utility in application environments [70]. Secondly, design science offers an effective means of addressing the relevancy gap that has plagued academic research, particularly in the management and information systems disciplines [70]. Our research is aimed to deduce a two-dimensional virtual fitting application which will support the decision making process of the shoppers when purchasing clothes online. This process could be contemplated as focusing human creativity into the design and construction of artifacts thus our research adheres to the aforementioned first ground of the design science research paradigmatic framework. Further our research is a collaborative effort of attempting to bridge the gap between available 3D virtual fitting applications and virtual fitting applications which would align with online marketplace. Therefore the research could be considered as an effort to address the relevance gap hence our research fits to the aforesaid second ground of the design science research paradigmatic framework. Based on these grounds our research conforms to the design science research paradigm.

3.2 Research Methodology

The primary focus of this study is to generate a fast online solution which will support the decision making process of human users, utilizing less computational power and less user intervention. The shopper is only required to provide the key body measurements of him or herself along with the selected garment item. These input body measurements of a particular user is the foundation of the human body model generation process which will be discussed later in this chapter.

The generated body model is then compared with a selected garment item which is available in the online shopping store. As a prerequisite of this proposed solution, the 2D models of the garment items of the online store are required to be generated and stored in a database.

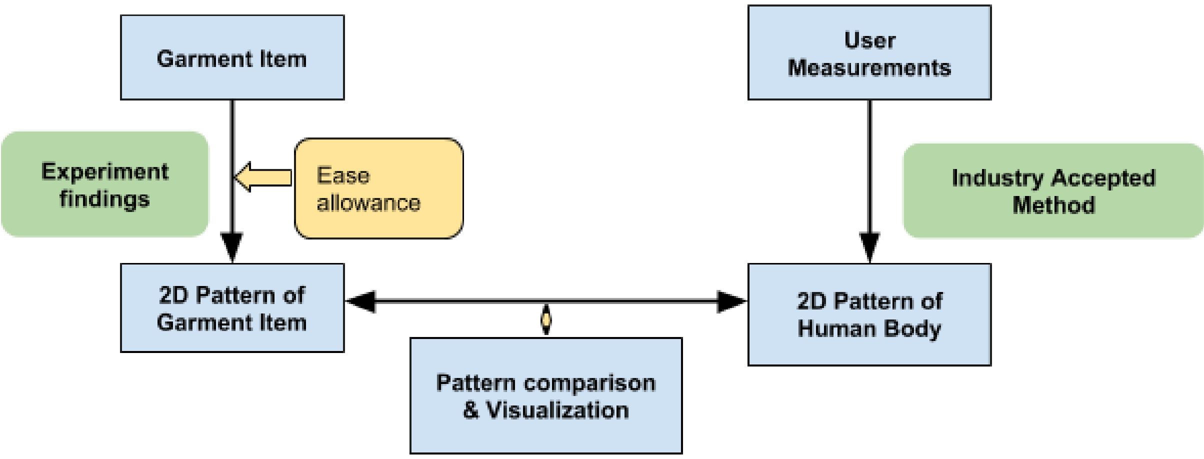


Figure 3.1. Methodology of the study

The following sections of this chapter will further discuss the methodology of the study starting from the generation of the garment model and human body model, and finally the comparison process of the two models.

3.3 Model Generation

The human body and the garment item were modelled in the same platform in order to carry out the comparison process more accurately. In order to represent the models of both human body and garment, a two-dimensional plane was selected as the platform. The concept behind this model generation is representing three dimensional objects using two-dimensional models preserving its original measurements. In this study two types of models were generated:

1. 2D Block Pattern of Garment Item
2. 2D Block Pattern of Human Body

3.3.1 2D Block Pattern of Garment Item

It is a known fact that garment items are made by sewing two-dimensional block patterns. The study focused on representing the garment items using its original 2D block pattern since each garment item is originated by a 2D block pattern. These block patterns contain the accurate measurements that are used to create garments. It is important to identify these accurate garment pattern measurements since these are necessary for the comparison process. In the first stage of the study a particular garment item was selected, and it was transformed into its block pattern upon identifying the relationship between the measurements of the finished garment and its block pattern (Figure 3.2).

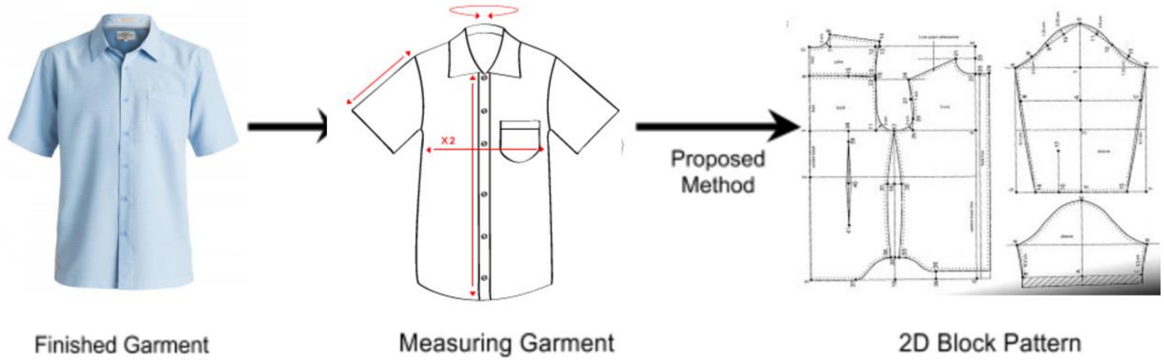


Figure 3.2. The process of transforming a short-sleeve shirt into its block pattern

An experiment was designed to examine the feasibility of the aforementioned process of transforming a specific clothing item into its block pattern. A male short-sleeve shirt was selected as the garment item for the first attempt of the experiment since it has been a frequent tailor making garment. Another reason for selecting short-sleeve men's shirt is that the design of the short-sleeve men's shirt is less complicated and it has less variations when compared to the available female garment patterns. This experiment was also aimed at analysing the relationship between the measurements of the finished garment and its block pattern. At the end of this experiment the 2D pattern of a finished short-sleeve men's shirt was obtained and plotted using a 2D Cartesian plane.

For the experiment ten short-sleeve men's shirts of same size, same design and same material were selected. The 16 measurements shown in Table 3.1 from the front, back and sleeve of the shirt were extracted using a measuring tape by placing the garment on a flat surface avoiding wrinkles.

Table 3.1. Measurements taken from the short-sleeve men's shirts

Front	**Back**	**Sleeve**
1. Length from Shoulder	8. Length from Middle	12. Upper Arm Length
2. Length from Middle	9. Length from Shoulder	13. Under Arm Length
3. Seam Length	10. Shoulder Width	14. Lower Girth * 2
4. Width from Hip Level	11.Length from Collar to Shoulder	15. Upper Girth * 2
5. Width from Waist Level		

6. Width from Chest Level		
7. Collar Width		

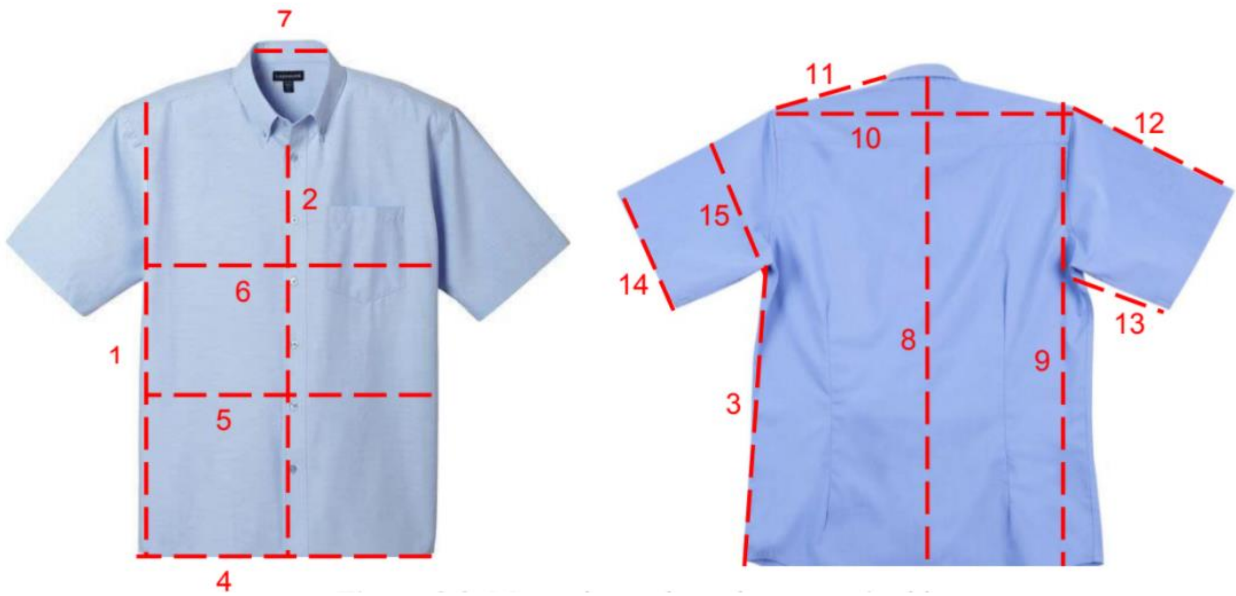


Figure 3.3. Measuring a short sleeve men’s shirt

After extracting all the necessary garment measurements shown in Figure 3.3, the sample shirts were converted into their pre-sewing stage by removing the stitches of the seams; the line where two garment pieces are sewn together. The block patterns of these unstitched garment pieces were drawn on a paper using a tracing wheel which is commonly used in flat pattern making field. Afterwards aforementioned 16 measurements were again extracted from the sketches of the block patterns. The differences between the measurements of the finished garment and measurements of the block pattern were analyzed to identify the relationship between the measurements.

3.3.1.1 Generalization of variance (Standard error values)

As aforementioned, for the standard method to convert a given short sleeve men's shirt, the error values that we got for each measurements of the shirt have to be generalized. For that first we calculated the error value for each and every measurement in every size by;

$$\textbf{\textit{Error Value}} = \textbf{\textit{Measurement of the finished Shirt}} - \textbf{\textit{Measurement of the unstitched block pattern of the shirt}} \tag{3.1}$$

Using equation 3.1, the error values for each and every measurement has been calculated and then to generalize these error values are plotted against the four sizes. This was done to every measurement and through that we were able to gain standard error value respecting to every measurement which can be generalized to all the short sleeve men's shirt (Table 3.2 – Table 3.15). Here the sizes are the independent variables (x) and error values of a measurement depends on it. Therefore it becomes the (y) axis. Based on the graphs for each measurement that is plotted using Minitab, we were able to take the equations that can be applied to get any error value for any selected type of shirt category. This can be identified as regression fit of the particular measurement and R-sq (R squared) which is known as statistical measure of how close the data are to the fitted regression line or the coefficient of determination/ the coefficient of multiple determination for multiple regression [71] can also be obtained.

➢ **Length from Shoulder - Front block**

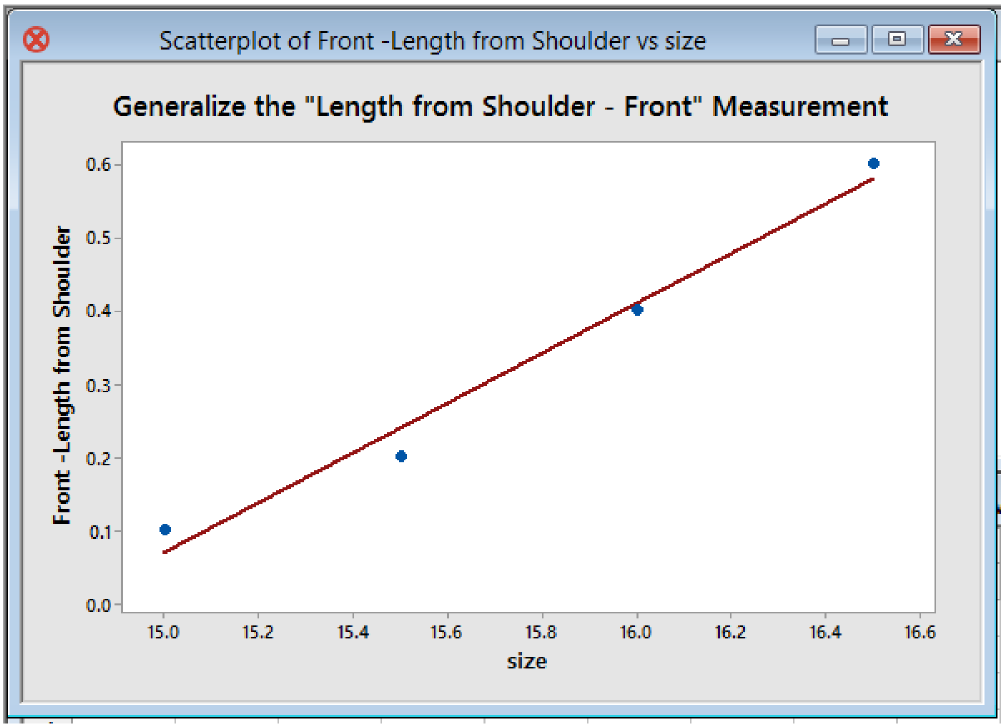


Figure 3.4. Generalization of Error in Length from Shoulder

Regression fit, Error = -5.030 + 0.3400 size

R-Sq = 98.0%

Table 3.2. Generalized values of length from shoulder measurement of the front of the shirt

Size	**Measured Error**	**Generalized Value**
15	0.1	0.07
15.5	0.2	0.24
16	0.4	0.41
16.5	0.6	0.58

➢ Length from Middle - Front block

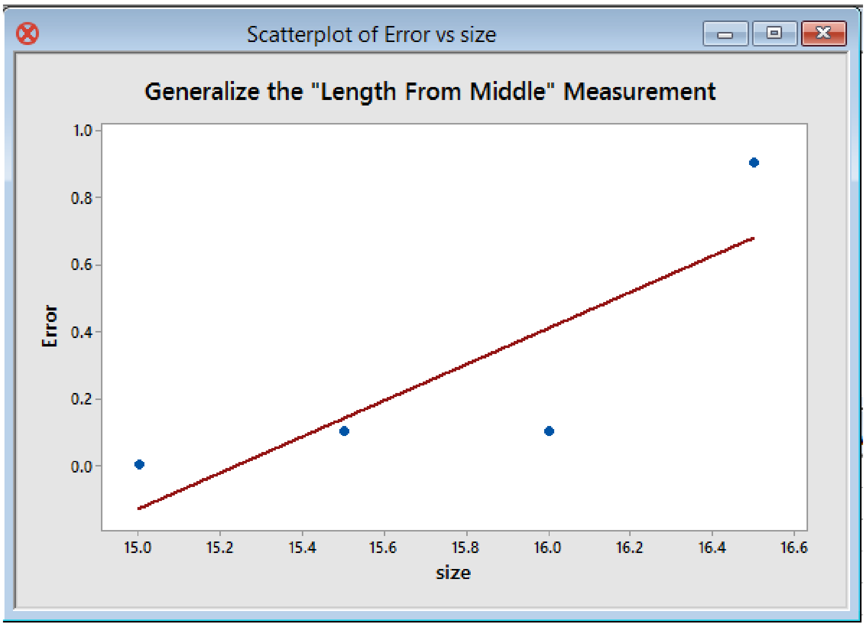


Figure 3.5. Generalization of Error in Length from Middle Measurement

Regression fit, Error = - 8.230 + 0.5400 size

R-Sq = 69.1%

Table 3.3. Generalized values of length from middle measurement of the front of the shirt

Size	Measured Error	Generalized Value
15	0	-0.13
15.5	0.1	0.14
16	0.1	0.41
16.5	0.9	0.68

➢ **Seam Length - Front block**

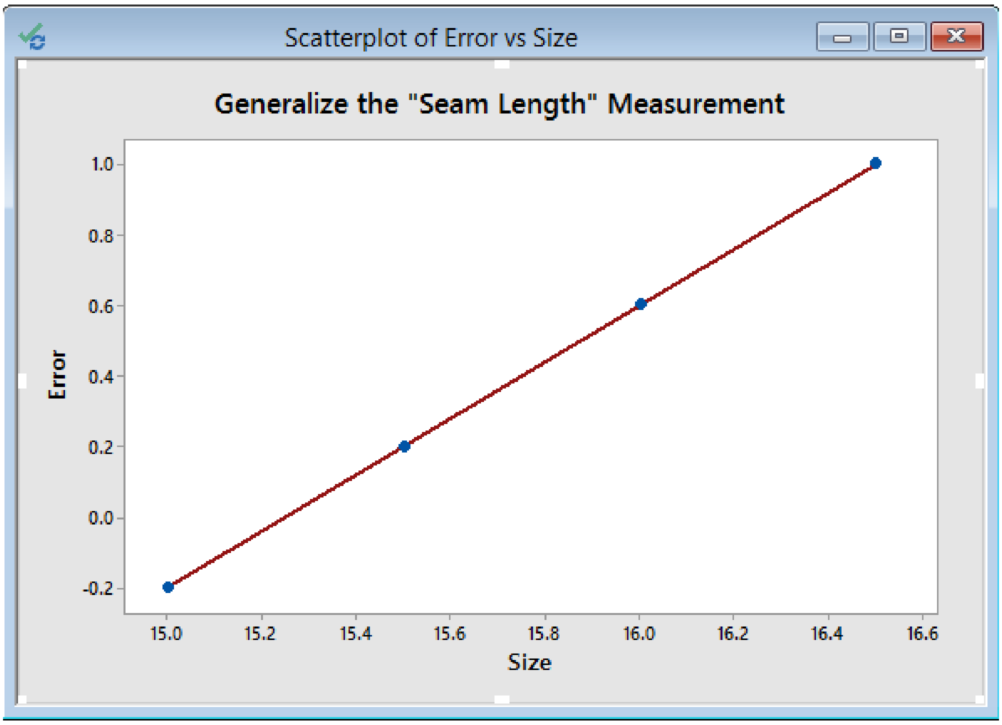


Figure 3.6. Generalization of Error in Seam Length Measurement

Regression fit, Error = - 12.20 + 0.8000 size

R-Sq = 100.0%

Table 3.4. Generalized values of seam length measurement of the front of the shirt

Collar Size	Measured Error	Generalized Value
15	-0.2	-0.2
15.5	0.2	0.2
16	0.6	0.6
16.5	1.0	1.0

➢ **Width from Hip Level - Front block**

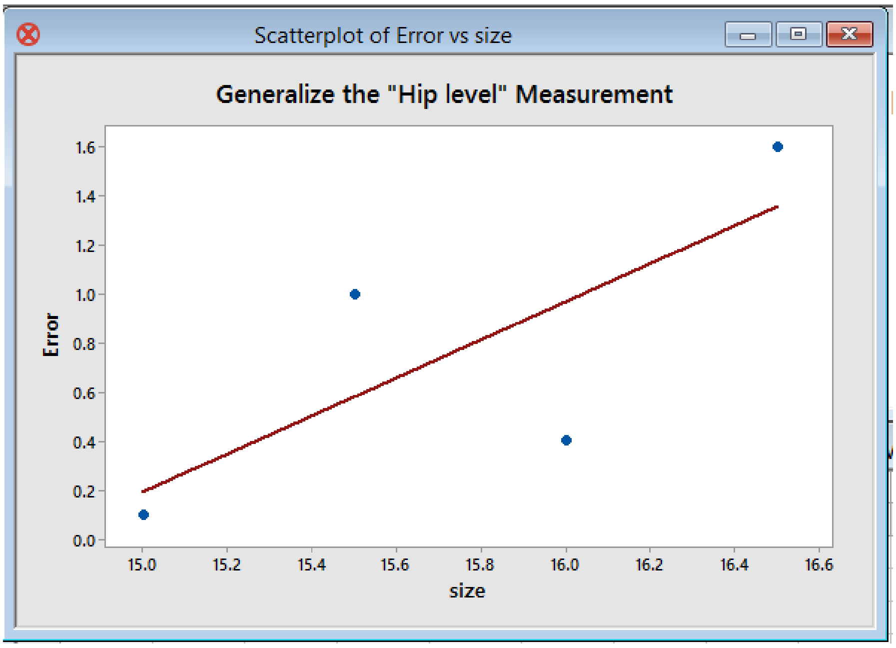


Figure 3.7. Generalization of Error in Width from Hip Level

Regression fit, Error = - 11.51 + 0.7800 size

R-Sq = 57.3%

Table 3.5. Generalized values of width from hip level measurement of the front of the shirt

Collar Size	Measured Error	Generalized Value
15	0.1	0.23
15.5	1	0.66
16	0.8	1.09
16.5	1.6	1.52

➢ **Width from Waist Level - Front block**

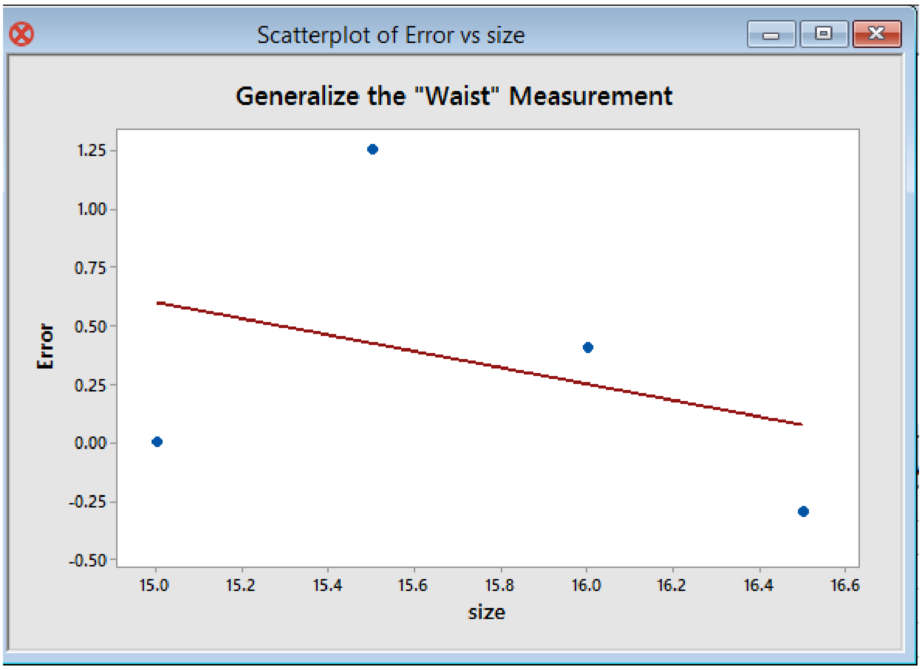


Figure 3.8. Generalization of Error in Width from Waist Level

Regression fit, Error = 5.85 - 0.3500 size

R-Sq = 11.3%

Table 3.6. Generalized values of width from waist level measurement of the front of the shirt

Collar Size	Measured Error	Generalized Value
15	0	0.64
15.5	1.25	0.50
16	0.8	0.37
16.5	-0.3	0.24

➢ **Width from Chest Level - Front block**

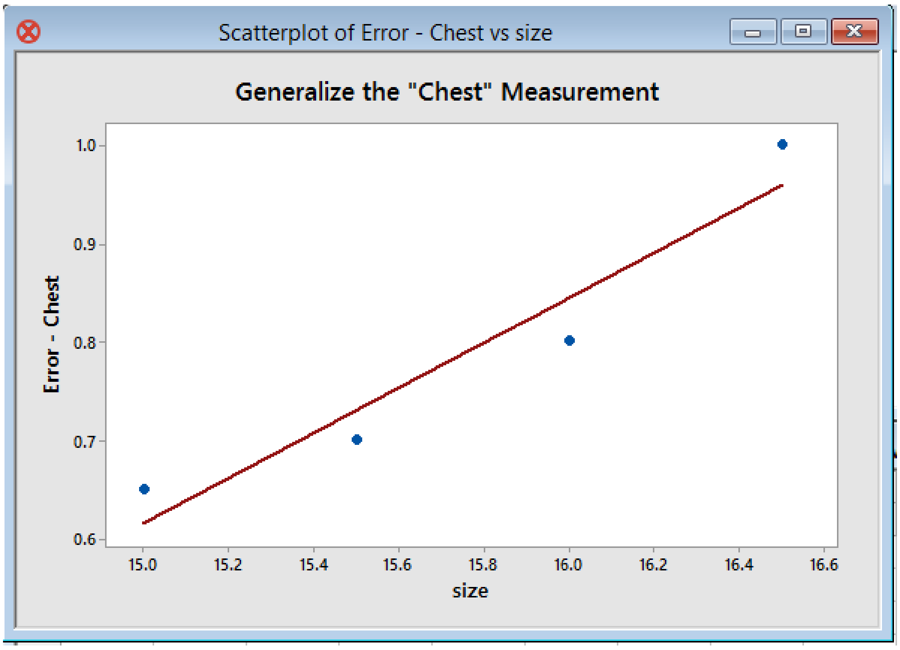


Figure 3.9. Generalization of Error in Chest Measurement

Regression fit, Error - Chest = - 2.835 + 0.2300 size

R-Sq = 92.0%

Table 3.7. Generalized values of width from chest level measurement of the front of the shirt

Collar Size	Measured Error	Generalized Value
15	0.65	0.695
15.5	0.7	0.89
16	1.6	1.085
16.5	1	1.28

➢ Collar Width - Front block

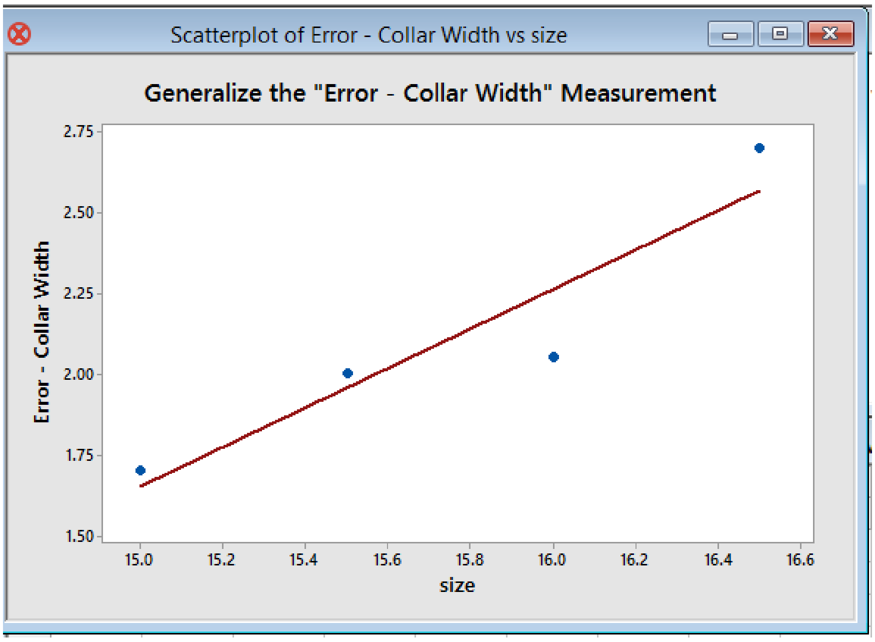


Figure 3.10. Generalization of Error in Collar Width measurement

Regression fit, Error - Collar Width = - 7.495 + 0.6100 size

R-Sq = 87.5%

Table 3.8. Generalized values of collar width measurement of the front of the shirt

Collar Size	Measured Error	Generalized Value
15	1.7	1.66
15.5	2	1.96
16	2.05	2.27
16.5	2.7	2.57

➢ Shoulder Width - Back block

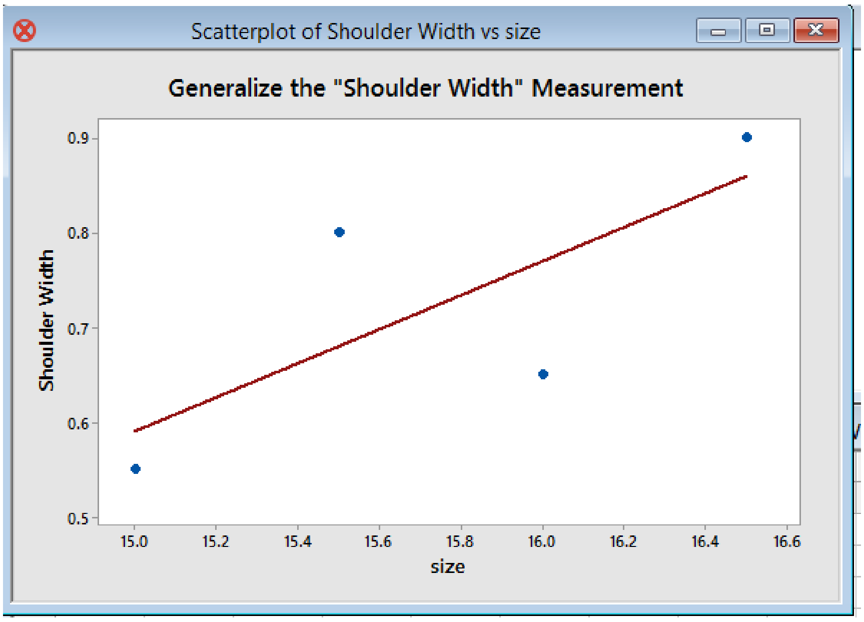


Figure 3.11. Generalization of Error in Shoulder width measurement

Regression fit, Shoulder Width = - 2.110 + 0.1800 size

R-Sq = 55.9%

Table 3.9. Generalized values of shoulder width measurement of the back of the shirt

Collar Size	Measured Error	Generalized Value
15	0.55	0.655
15.5	0.8	0.81
16	1.3	1.12
16.5	0.9	0.965

➢ Length from Middle - Back block

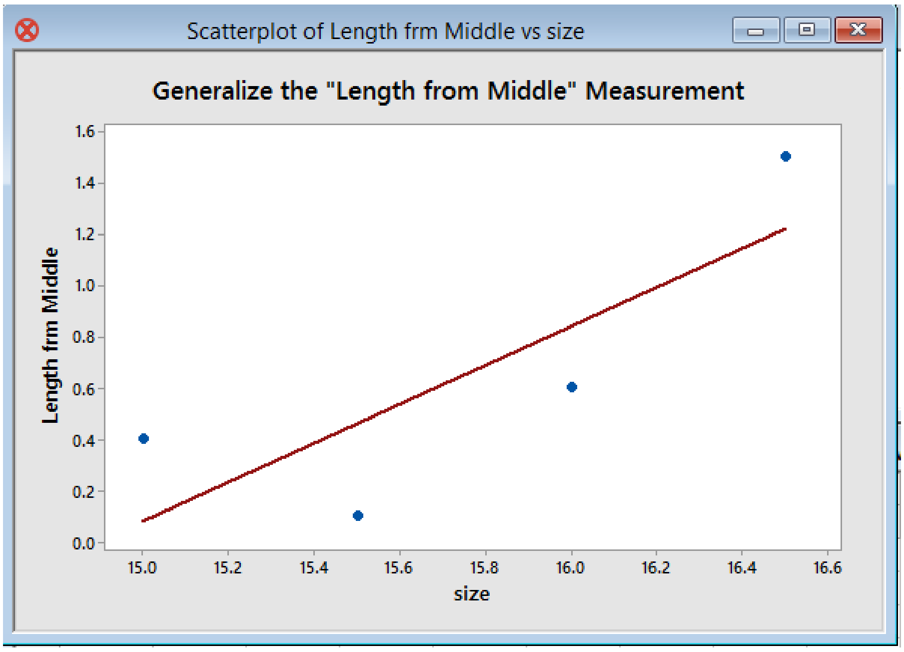


Figure 3.12. Generalization of Error in Length from Middle measurement

Regression fit, Length from Middle = - 11.32 + 0.7600 size

R-Sq = 66.2%

Table 3.10. Generalized values of length from middle measurement of back of the the shirt

Collar Size	**Measured Error**	**Generalized Value**
15	0.4	0.08
15.5	0.1	0.46
16	0.6	0.84
16.5	1.5	1.22

➢ Length from Shoulder - Back block

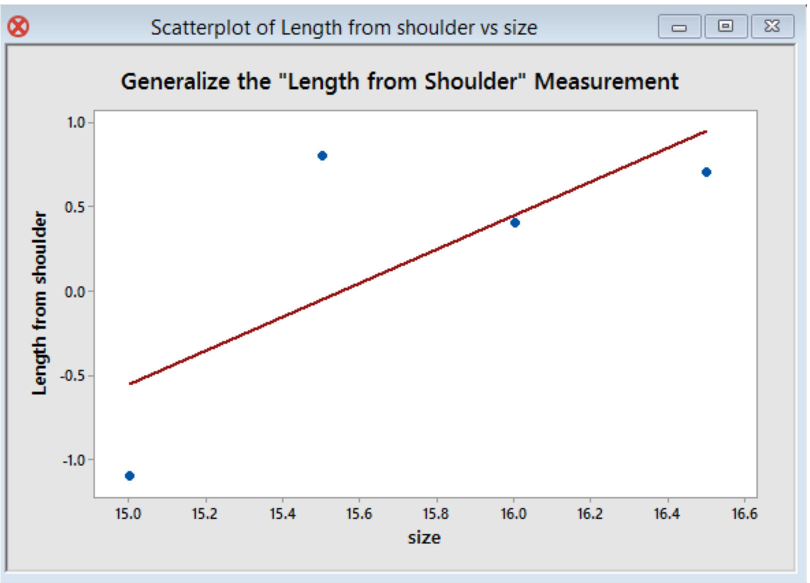


Figure 3.13. Generalization of Error in Length from Shoulder Measurement

Regression fit, Length from shoulder = - 15.55 + 1.000 size
R-Sq = 53.4%

Table 3.11. Generalized values of length from shoulder measurement of back of the shirt

Collar Size	Measured Error	Generalized Value
15	-1.1	-0.55
15.5	0.8	-0.05
16	0.4	0.45
16.5	0.7	0.95

➢ **Lower Girth Measurement - Arm block**

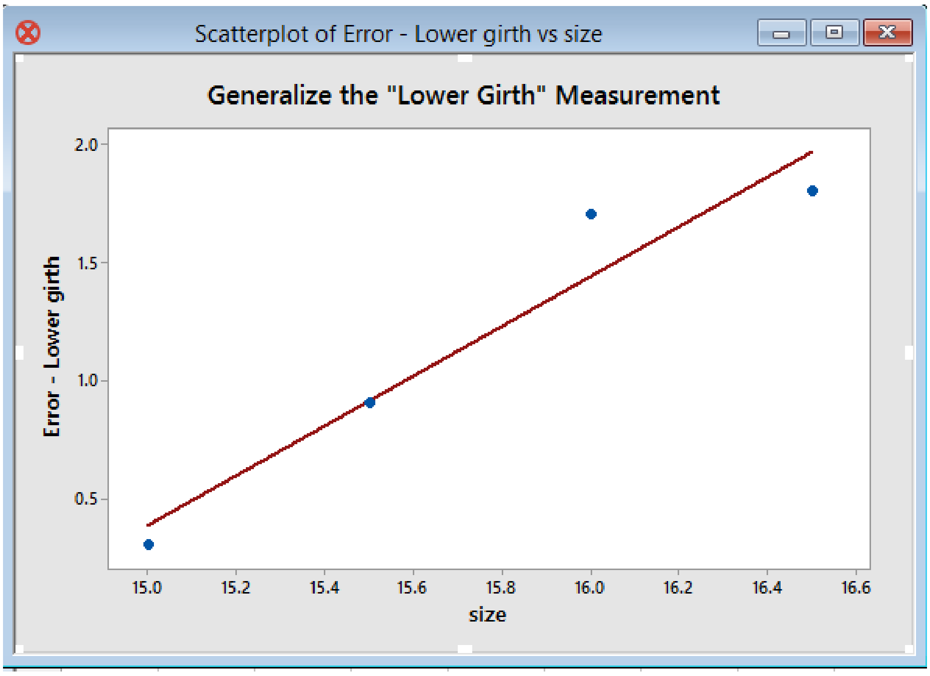


Figure 3.14. Generalization of Error in Lower Girth Measurement

Regression fit, Error - Lower girth = - 15.52 + 1.060 size

R-Sq = 93.2%

Table 3.12. Generalized values of lower girth measurement of arm of the shirt

Collar Size	Measured Error	Generalized Value
15	0.3	0.38
15.5	0.9	0.91
16	1.7	1.44
16.5	1.8	1.97

➢ Under Arm Length Measurement - Arm block

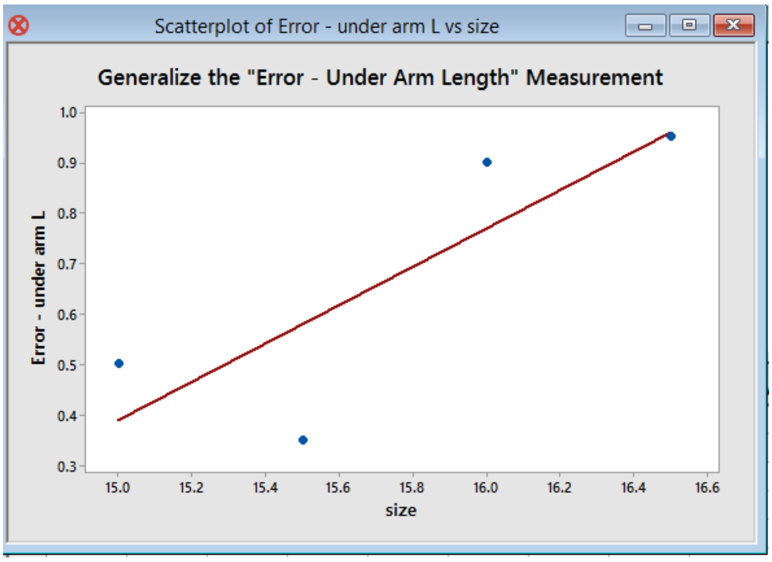


Figure 3.15. Generalization of Error in Under Arm Length Measurement

Regression fit, Error - under arm Length = - 5.310 + 0.3800 size

R-Sq = 68.8%

Table 3.13. Generalized values of under arm length measurement of arm of the shirt

Collar Size	Measured Error	Generalized Value
15	0.5	0.39
15.5	0.35	0.58
16	0.9	0.77
16.5	0.95	0.96

➢ Upper Arm Girth - Arm block

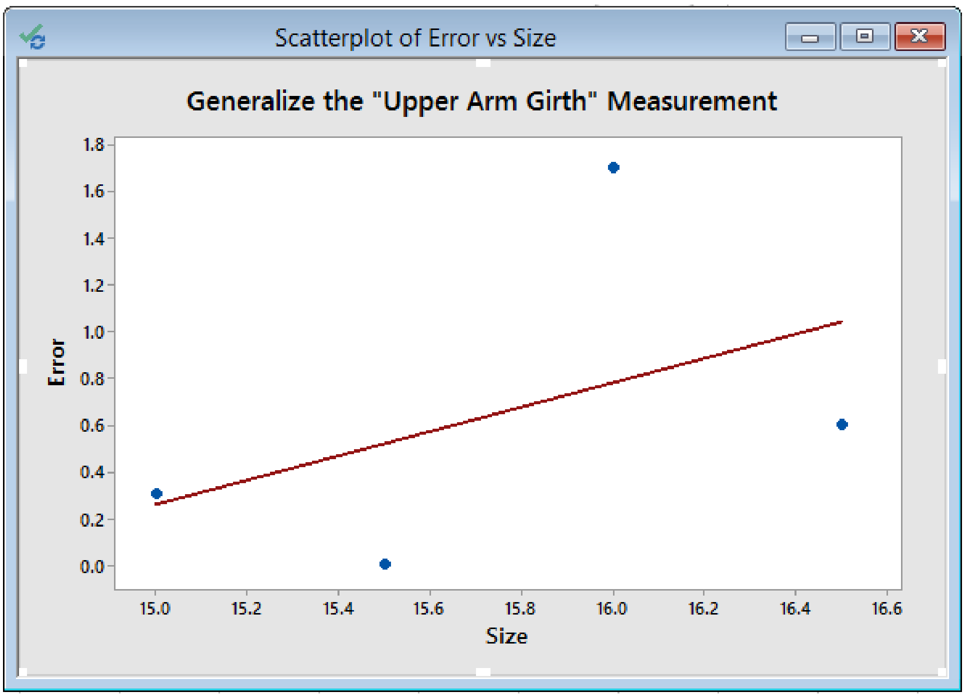


Figure 3.16. Generalization of Error in Upper Arm Girth Measurement

Regression fit, Error - Upper arm girth = - 7.54 + 0.5200 size

R-Sq = 20.5%

Table 3.14. Generalized values of upper arm girth measurement of arm of the shirt

Collar Size	Measured Error	Generalized Value
15	0.3	0.26
15.5	0	0.52
16	1.7	0.78
16.5	0.6	1.04

➢ **Upper Arm Length - Arm block**

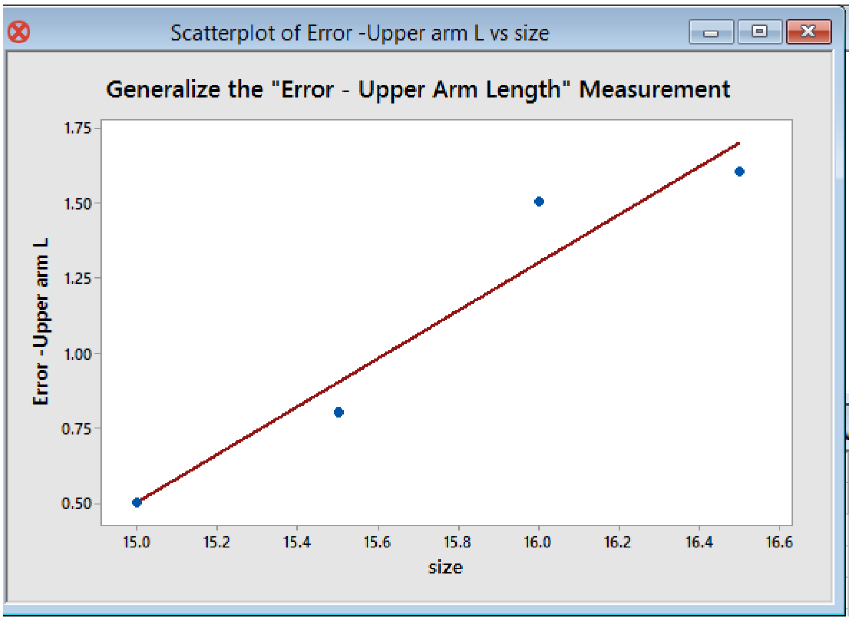


Figure 3.17. Generalization of Error in Upper Arm Length Measurement

Regression fit, Error -Upper arm Length = - 11.50 + 0.8000 size

R-Sq = 93.0%

Table 3.15. Generalized values of upper arm length measurement of arm of the shirt

Collar Size	Measured Error	Generalized Value
15	0.5	0.5
15.5	0.8	0.9
16	1.5	1.3
16.5	1.6	1.7

Upon identifying this relationship a standard method was proposed for converting a given short sleeve men's shirt into its two-dimensional block pattern. Based on these measurements, 2D patterns of the front (Figure 3.18), back (Figure 3.19) and arm (Figure 3.20) of the short sleeve shirt was modelled. Following are the generalized 2D block patterns for a short sleeve shirt which can be used to represent the relationship of converting the finished garment item (Men's short sleeve shirt) to its 2D block pattern with equations for front (Table 3.16), back (Table 3.17) and the sleeve (Table 3.18) of the shirt separately.

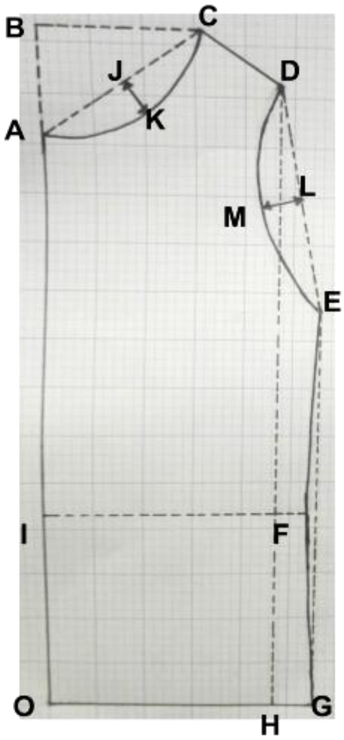


Figure 3.18. Half - Front block of the shirt

Table 3.16. Equations to derive the Front block of the shirt

OA	**Length from the middle of the garment + b**
AB	**(Back length from the middle - Front length from the middle)**
BC	**Collar width of the garment / 2**
CD	**Length from collar to shoulder of the garment**
DH	**Length from shoulder to hip of the garment +e**
OI	**(Seam length + d) / 2**
OG	**(Lower width of the garment +a) / 2**
IF	**(Waist of the garment + c) / 2**
AC	**$(AB^2 + BC^2)^{1/2}$**
JK	**3.5 cm**
ML	**4.5 cm**

ACK and DME curves can be calculated using the equation; $\mathbf{y = ax^2+bx+c}$

JK and ML values are constants and a, b, c, d, e are the values of standard mean errors between the front block and the front of the shirt

a=0.4cm b=0.9cm c=-0.8cm d= 1.0cm e=0.9cm

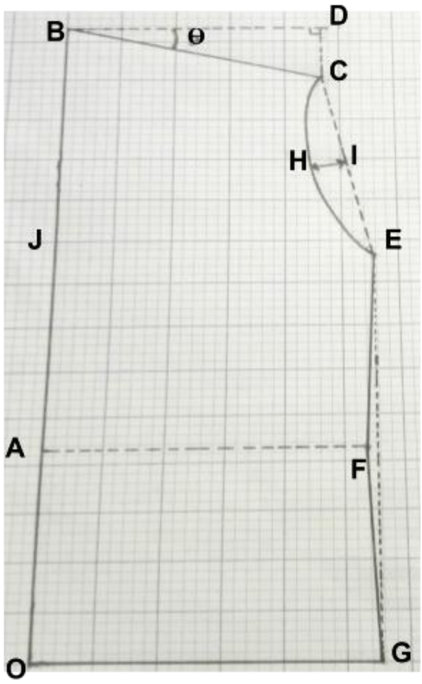


Figure 3.19. Half - Back block of the shirt

Table 3.17. Equations to derive the Back block of the shirt

OA	**(Seam length of the garment + d) / 2**
OB	**Back length of the middle of the garment + b**
BC	**Mid neck to shoulder of the garment + k**
BD	**(Full shoulder width of the garment + j) / 2**
DC	**n**
EG	**Seam length of the garment + d**
JE	**(Chest of the garment + c) / 2**
AF	**(Waist of the garment + c) / 2**

OG	**(Lower width of the garment + a) / 2**
HI	**3.5 cm**

$$\cos\theta = BD \;/\; BC$$
$$\theta = \cos^{-1} BD / BC$$
$$\tan\theta = n / BD$$
$$n = \tan\theta\,(BD) \qquad (3.2)$$

CHE curve can be calculated using the equation; $\mathbf{y = ax^2+bx+c}$

HI value is a constant one and a, b, c, d, e, j, k are the values of standard mean errors between the back block and the back of the shirt.

a= 0.4 b=1.5 c=1.4 d=1 e= -0.8 j=0.6 k=1.5

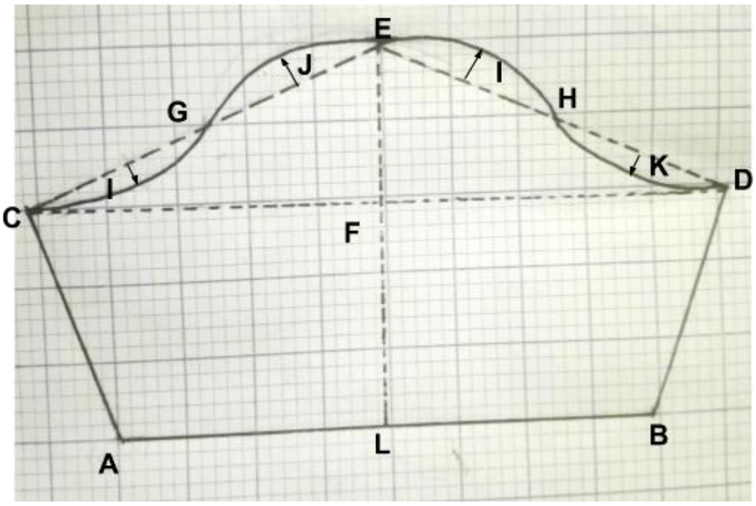


Figure 3.20. Sleeve block of the shirt

Table 3.18. Equations to derive the Sleeve block of the shirt

AB	**Lower arm girth of the garment + x**
CF	**(Upper arm girth of the garment + x) / 2**
LE	**Upper arm length of the garment + y**
FL	**Under arm length of the garment + z**
I	**1.25 cm**

J	**1.6 cm**
K	**0.9 cm**

I, J, K are constant values and x, y, z are standard mean errors of the sleeve block and the sleeve of the shirt

x= 1.7 y=0.5 z=0.15

3.3.1.2 Results of the Experiment - Short sleeve shirt

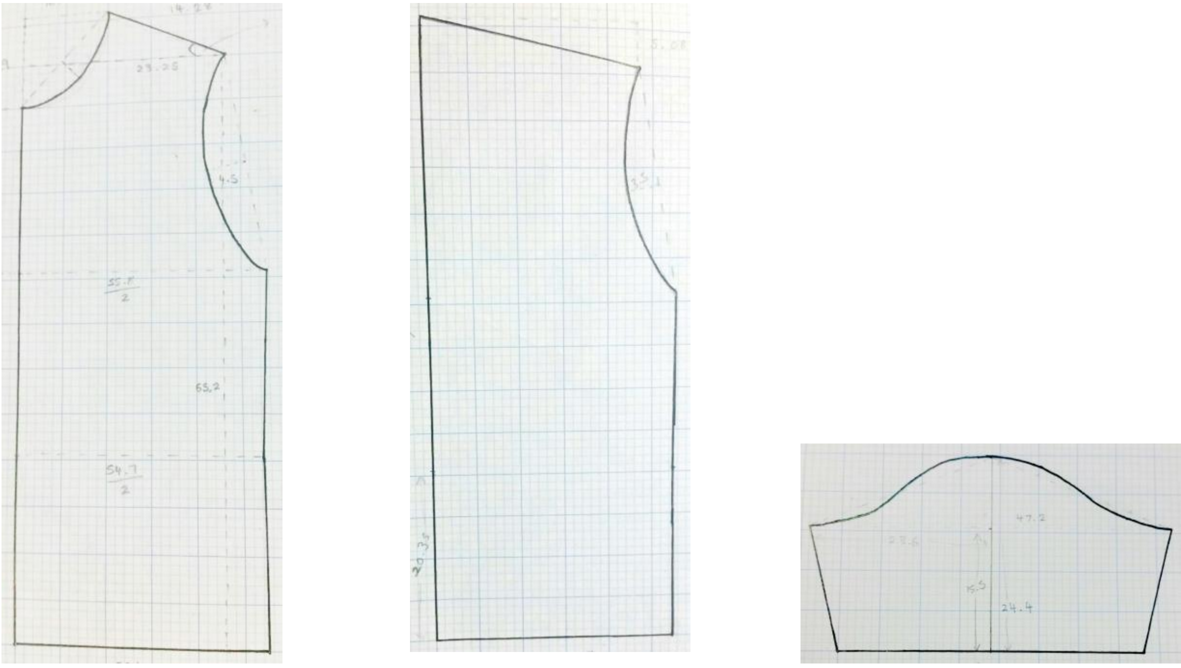
A short sleeves men's shirt with the collar size of 16 inches was selected to be used in the case studies. As the first step of the process of generating the 2D model of the shirt, 15 measurements (Table 3.19) were extracted from this particular shirt with the use of a tape measure. The shirt was placed on a flat surface and the wrinkles were avoided in order to obtain the accurate measurements of the shirt.

Table 3.19. Measurements of the garment

	Measurement	**Value (cm)**
	Front Measurements	
1.	Length from Shoulder	65.1
2.	Length from Middle	60
3.	Seam Length	40.7
4.	Width from Hip Level	55
5.	Width from Waist Level	54.8
6.	Width from Chest Level	55.6
7.	Collar Width	18.3
	Back Measurements	
8.	Length from Middle	70.9
9.	Length from Shoulder	65.3
10.	Shoulder Width	46.5
11.	Length from Collar to Shoulder	18.5
	Sleeve Measurements	
12.	Upper Arm Length	24.4
13.	Under Arm Length	15.1
14.	Lower Girth	37.8

15.	Upper Girth	46.6

By taking the above measurements (Table 3.19) and applying them to the equations that are derived from the experiment the 2D pattern of the shirt is created as shown in Figure 3.21.



(a) (b) (c)

Figure 3.21. (a) Front half of the shirt, (b) Back half of the shirt, (c) Sleeve of the shirt

3.3.2 2D Block Pattern of Human Body

Initially, the study will be conducted focusing only males since the males have standard patterns for their garment items more than females. Males also prefer selecting the garment items within a very short period of time and they do not like to spend time by waiting in the queues to fit on the garments.

In order to compare the human body with the 2D model of the garment item the model of the human body was transformed into the same 2D platform. In the Garment Pattern Making Industry the scientific method for creating ‘close fitting basic bodice block’ is used to make garments that are tightly fitted to the male upper body; from base of the neck to waist, excluding arms. Only the upper body of males was modelled as a basic garment pattern with the use of aforementioned ‘close-fitting basic bodice block’ creation method [72] because of its significant similarity with the representation of male upper body. 15 body measurements (Table 3.20) of male upper body were selected in order to generate this 2D bodice block which is the exact replica of the corresponding user's upper body as the measurements are taken with zero ease allowance (Figure 3.22).

Figure 3.22. Standard male body measurements

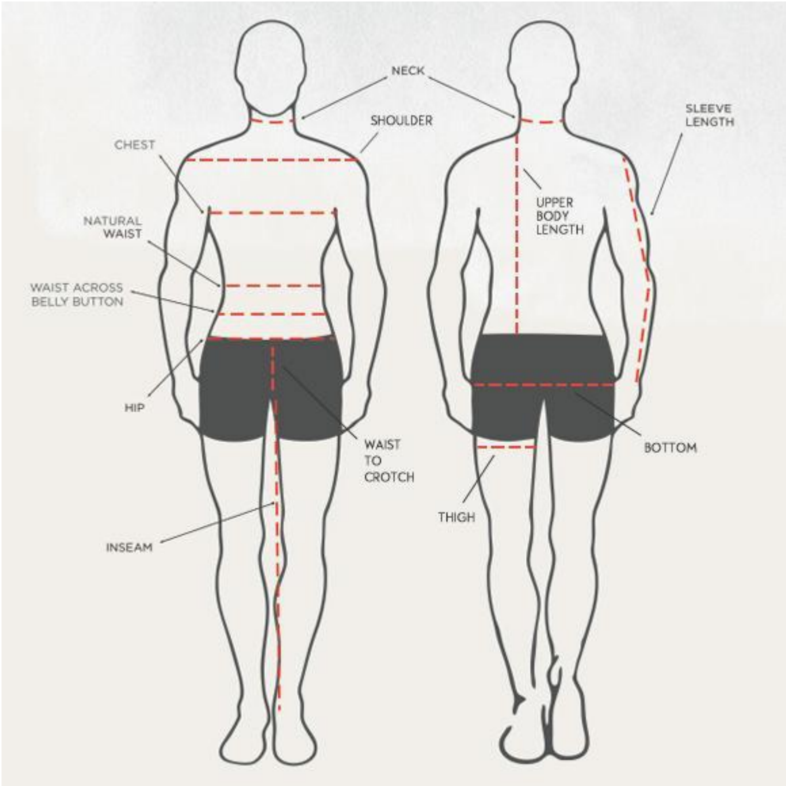


Table 3.20. Definitions of the body measurements

Measurement	Definition
1.Neck girth	The neck measurement is taken around the neck with the tape resting on your shoulders. You should put one finger between the tape and the neck if you want to allow for some extra room
2.Neck base width	The neck base width measurement is taken from the middle of the neck to the shoulder in the front
3.Chest	The chest measurement is taken as a circumference measurement around your chest at the widest point. Stand in a relaxed posture and breathe out
4.Hip	The hip measurement is taken as a circumference measurement around your hips at the widest part
5.Waist	The waist measurement is taken as a circumference measurement around your waist just above your belly button. Stand in a relaxed posture and breathe out

6.Side Shoulder-to waist	Length from the shoulder to the waist. Here, the shoulder point is taken as the edge of shoulder
7.Side neck-to-waist	Length from the side of the neck to the waist. Here, side of the neck is the widest side of the neck
8.Waist-to-hip	Length from waist to hip
9.Underarm-to-waist	Length from the under arm to the waist. Here, underarm is the lowest point of the arm hole.
10.Arm hole	Think of a line going from your armpit straight upwards to your shoulder. Measure between those two points and hold the tape measure straight
10.Shoulder width	Length between shoulder points. A shoulder point is where the horizontal part of the shoulder meets the vertical part of the arm
11.Shoulder width	The length from the shoulder point to the approximate middle point from the shoulder point and elbow which is taken in the arm girth.
12.Upper arm length	The length from the armpit to the approximate middle point from the shoulder point and elbow which is is taken in the arm girth.
13.Under arm length	The measurement is taken as the circumference of the largest point of the bicep. Here, approximate middle point from the shoulder point and elbow is taken.
14. Lower Arm girth	The circumference of the upper part of the bicep

Based on these measurements, 2D patterns of the front (Figure 3.23), back (Figure 3.24) and arm (Figure 3.25) of the human body were modelled. Following are the generalized 2D block patterns for a male upper body which can be used to represent different male upper bodies. These 2D patterns contributed to generate the equations shown in Table 3.21, Table 3.22 and Table 3.23.

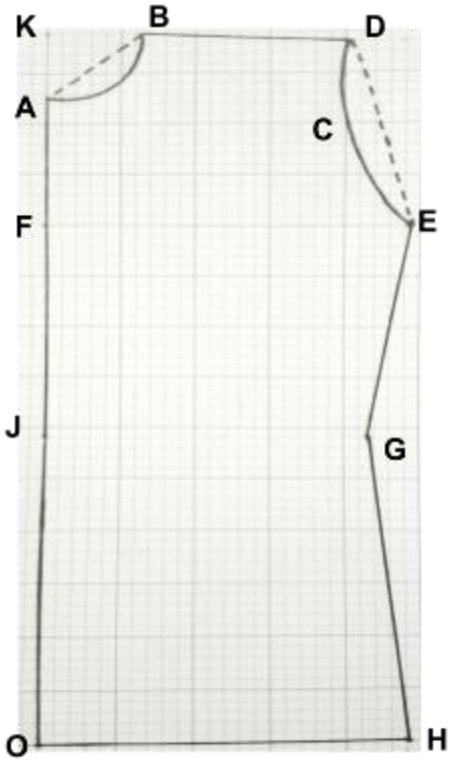


Figure 3.23. Half - Front block of Human

Table 3.21. Equations to derive the Front block of human

KJ	**Side neck to waist**
JO	**Waist-to-hip**
AK	**(Neck girth / 6) + 0.5**
BK	**(Neck girth / 6) + 0.5**
KD	**Neck base width / 2**
FE	**((Chest/2)+1) / 2**
JG	**((Waist/2)+1) / 2**
OH	**((Hip/2)+1) / 2**
EG	**Underarm-to-waist**
DCE	**(Armhole / 2) - 0.5**

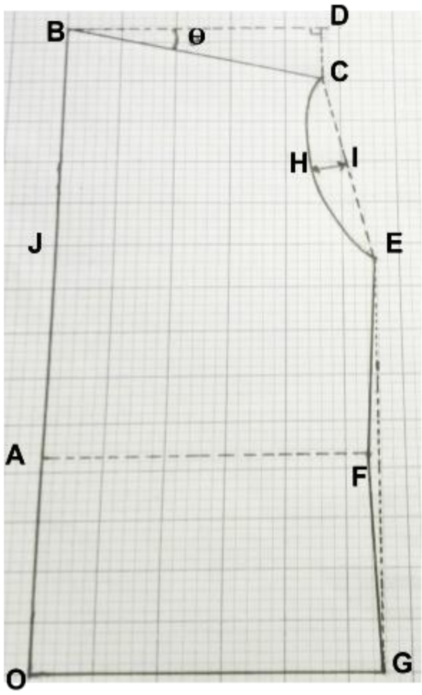


Figure 3.24. Half - Back block of Human

Table 3.22. Equations to derive the Back block of human

DC	**Side neck to waist**
CO	**Waist-to-hip**
AD	**2cm**
DE	**(Neck girth / 6) + 0.5**
DF	**Neck base width / 2**
BG	**((Chest/2)-1) / 2**
CI	**((Waist/2)-1) / 2**
OJ	**((Hip/2)-1) / 2**
GI	**Underarm-to-waist**
DCE	**(Armhole / 2) - 0.5**

Male arm was modelled as a basic garment pattern with the use of the 'close-fitting sleeve block' creation method [72]. Four measurements of male arm including upper arm length, under arm length, upper arm girth and lower arm girth were chosen in order to generate the aforementioned 2D sleeve block (Figure 3.25), which can be considered as an exact model for the corresponding user's arm.

The following equations (Table 3.23) were generated based on the 'close-fitting sleeve block' creation method.

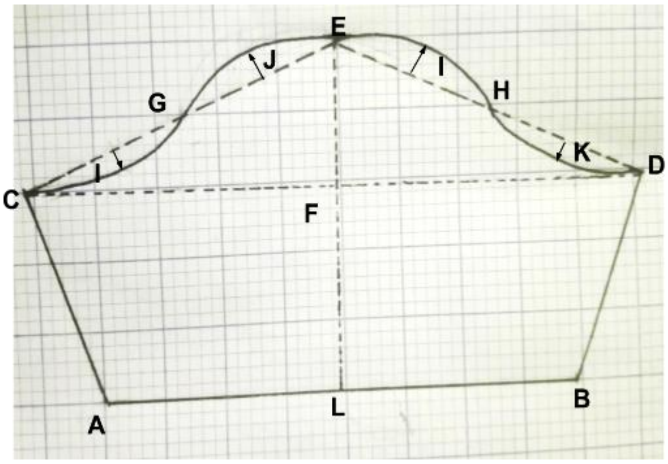


Figure 3.25. Arm block of Human

Table 3.23. Equations to derive the Sleeve block of human

EG	**Lower arm girth**
AD	**(Upper arm girth of the garment + x) / 2**
DF	**Under arm length**
BF	**Upper arm length**
H	**1.25 cm**
I	**1.5 cm**
J	**1.25 cm**
K	**0.9 cm**

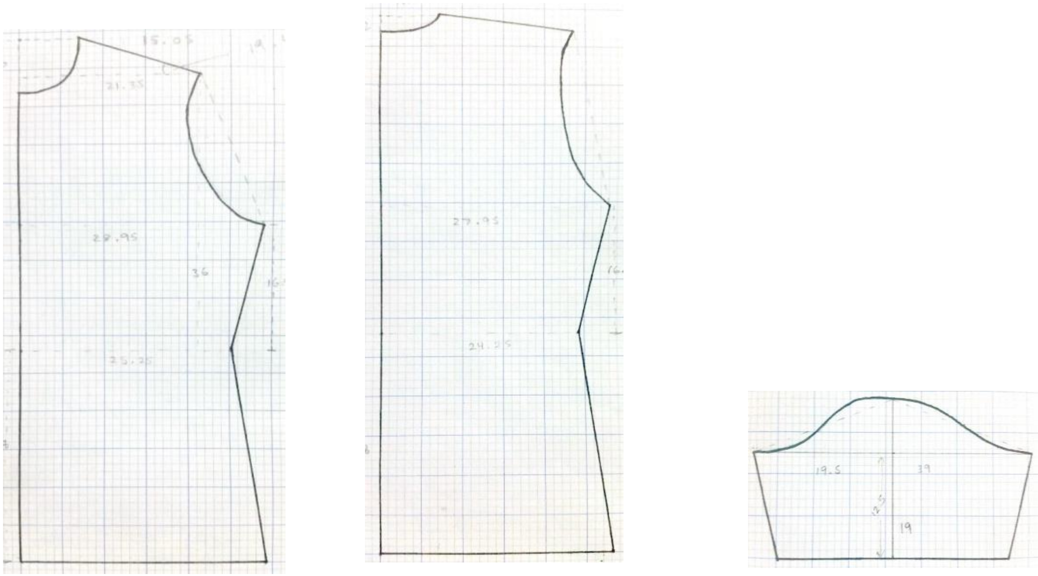
3.3.2.1 Results of the Experiment - Human body pattern

Using the scientific method that has been described in the previous section, the 2D pattern of the human body has been generated for the selected three participants for their upper body and the upper arm. This 2D pattern is known as the close fitting basic bodice block.

Table 3.24. Measurements of the selected participants

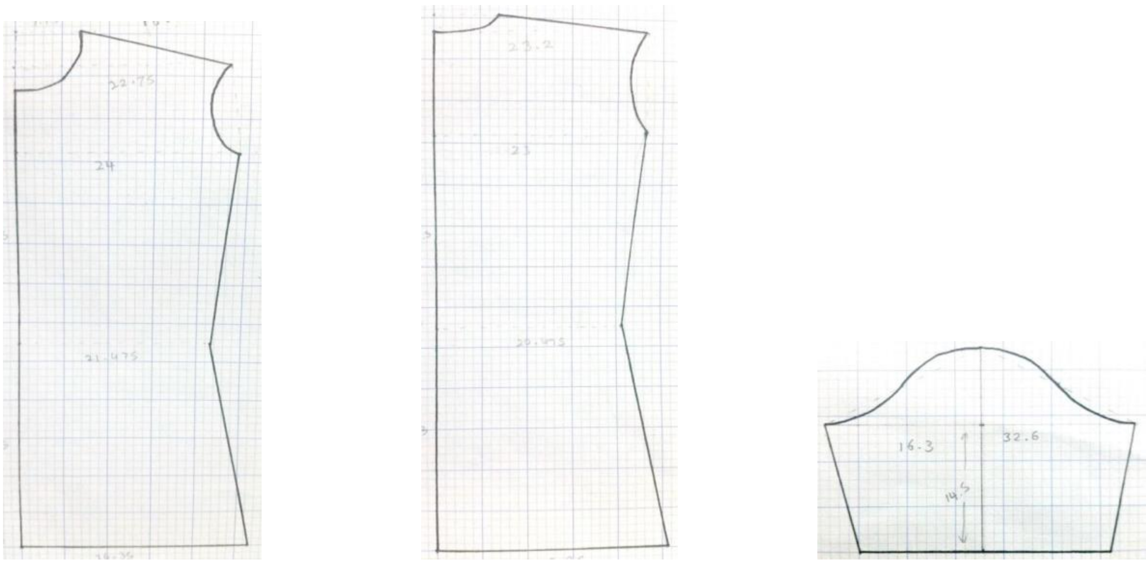
	Measurements	Values(cm)		
		Participant 01	Participant 02	Participant 03
1.	Neck girth	40	39.8	37
2.	Neck base width	42.7	45.5	40.5
3.	Chest	113.8	94	80.6
4.	Hip	114.5	103.4	87.9
5.	Waist	99	83.9	66.2
6.	Side Shoulder-to waist	36	34	31
7.	Side neck-to-waist	41	38.5	35.5
8.	Waist-to-hip	28	27.3	27
9.	Underarm-to-waist	16.5	23.5	20.5
10.	Arm hole	50.3	38.7	37.5
11.	Shoulder width	46.8	46.4	40.2
12.	Upper arm length	19	22.5	21
13.	Under arm length	12.5	14.5	15
14.	Lower Arm girth	32.2	25.9	22.5
15.	Upper arm girth	39	32.6	26.8

Taking the input measurements (Table 3.24) of participant 01, participant 02 and participant 03 following 2D patterns for the front, back and the arm has been created separately as shown in Figure 3.26, Figure 3.27 and Figure 3.28 using the equations that has been derived in the experiment.



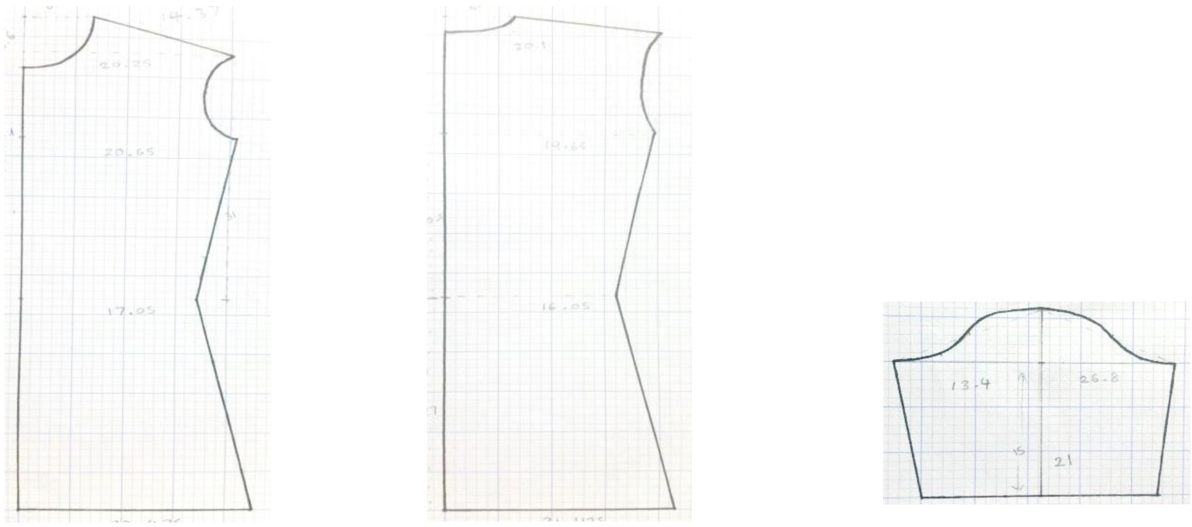
(a) (b) (c)

Figure 3.26. Participant 01(a) Front half of the body, (b) Back half of the body, (c) Upper Arm



(a) (b) (c)

Figure 3.27. Participant 02 (a) Front half of the body, (b) Back half of the body, (c) Upper Arm

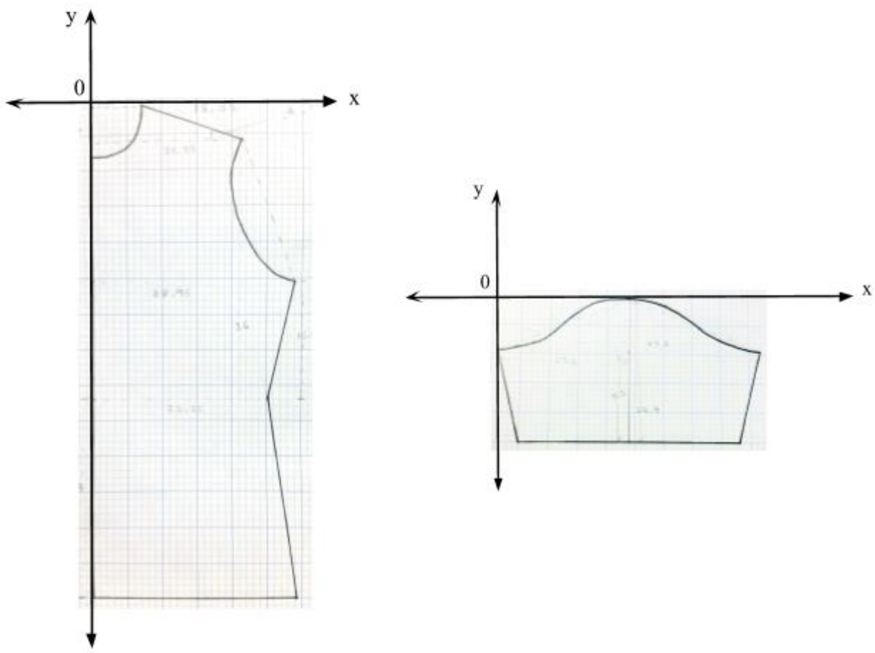


(a) (b) (c)

Figure 3.28. Participant 03 (a) Front half of the body, (b) Back half of the body, (c) Upper Arm

3.4 Model Comparison and Usage of Distance Ease

The two-dimensional block patterns of male short-sleeve shirt and human body were compared by plotting them on a 2D Cartesian plane as shown in the Figure 3.29.

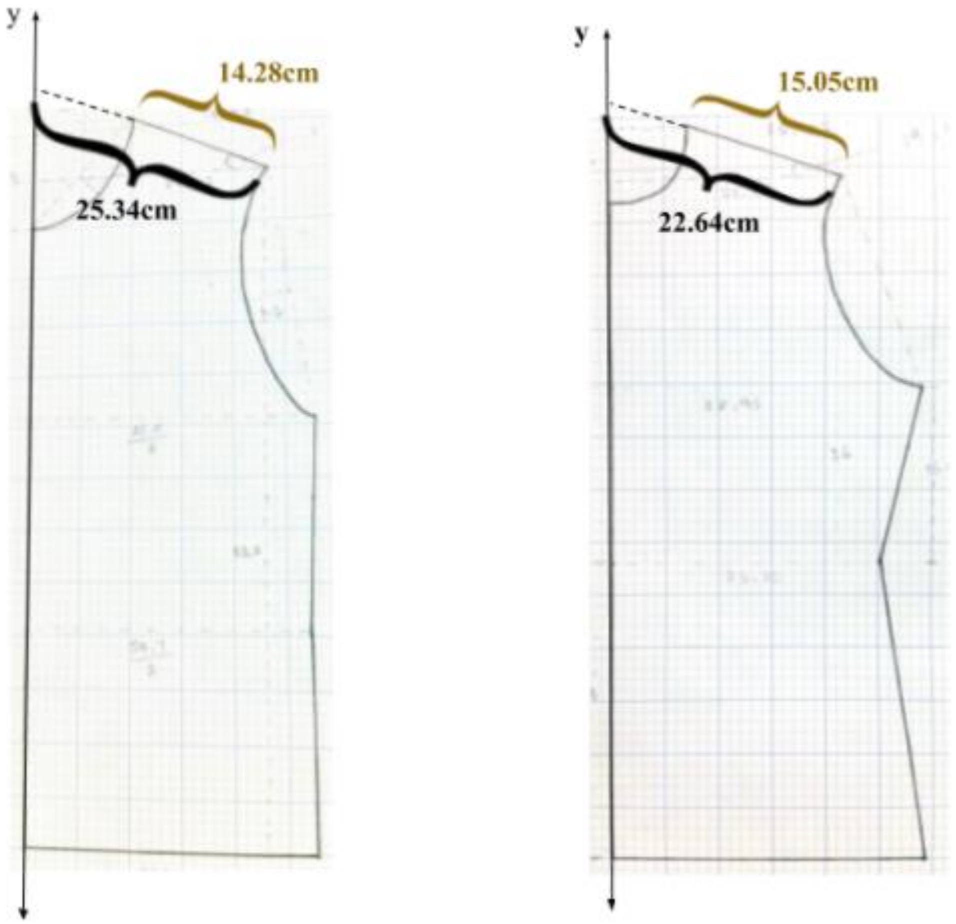


(a) (b)

Figure 3.29. Plotting the block patterns on a 2D Cartesian plane

For the comparison process, the areas of a shirt with most fitting issues were considered such as Shoulder, Chest, Waist, Hip and Arm. These problematic areas were identified through a survey which was distributed among male university students. As the next step of the comparison process the relevant numerical points of the two models with respect to the most problematic fitting areas were identified. The main challenge was identifying these corresponding Cartesian coordinates. The 2D patterns were modelled as shown in Figure 3.29 by aligning the upper-most point with x-axis, and aligning the leftmost point or line with the y-axis of the coordinate system. The reason for aligning the 2D block patterns with the x-axis and y-axis is that it enables much easier pattern comparison by providing common starting measuring points. For example, when comparing the length of the shirt with the human body, the length of the shirt of the front 2D pattern (DH) was compared with the summation of the side neck to waist (KJ) and waist to hip (JO) lengths in the front human body pattern. But, when comparing the shoulder widths of the human body and the shirt a different mechanism was utilized. The shoulder width depicted in the front block of the shirt was 14.28cm. The shoulder widths depicted in the front block of the participants were 15.05cm, 16.26cm and 14.37cm. As the human measurements were larger than the garment measurements, these measurements were not used directly to provide insights regarding the shoulder width fit. So, the shoulder lines of the patterns were extended till they meet the y-axis. The new values of the extended shoulder lines are given below (Figure 3.30).

Shirt	= 25.34cm
Participant 01	= 22.64cm
Participant 02	= 23.68cm
Participant 03	= 21.32cm



(a) (b)

Figure 3.30. Measuring shoulder width (a) Front half of Shirt, (b) Front half of Participant 01

Upon identifying these numerical points or Cartesian coordinates, the relevant distance values of both models were extracted. The generalized errors which were calculated for each measurement were added to the distance values extracted from the shirt's block patterns. After calculating these new values, they were compared with the distance values extracted from the block patterns of the human body in order to estimate the fit of the particular garment to that user.

The comparison process was conducted under two main phases. In the first phase the front block of the garment was compared with the front block pattern of the human upper body. In the second phase the sleeve block of the garment was compared with the sleeve block pattern of the human upper arm. Moreover the ease measurements to classify the fitness of the garment has also been proposed in this process based on the literature and ease values for each measurements have been contextualized to the research. The comparison processes conducted under these both phases are furthermore discussed in the following sections.

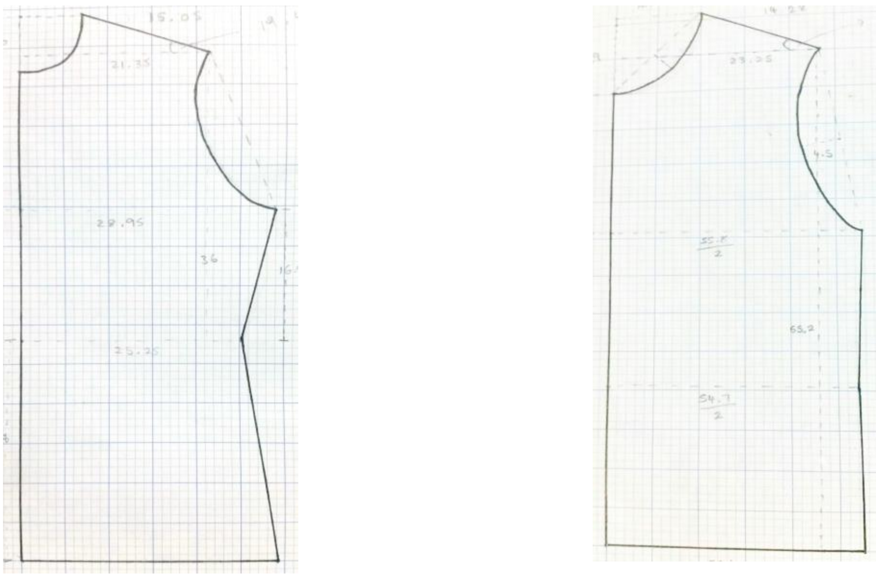
3.4.1 Results comparison of the Experiment

In the comparison process, the above generated two-dimensional block patterns of male short-sleeve shirt and human body were compared using five main sections which have been defined as Shoulder, Chest, Waist, Hip and Arm. The length of the two-dimensional patterns of shirt and human body were compared only if the measurements of aforementioned points got matched.

As aforementioned, three different participants having different body sizes were selected as case studies and two-dimensional block patterns of these participants have been generated. The same shirt was used for all these three case studies and two-dimensional block pattern of the shirt was also generated. The two-dimensional block patterns of shirt and participants were compared using the above process and below results have been obtained which are shown in Table 3.25, Table 3.26 and Table 3.27. After that, the selected shirt was fitted-on by the three participants whom we have selected for our study. The results obtained from the 2D pattern comparison were then validated with the fit-on trials.

3.4.1.1 Case Study 01

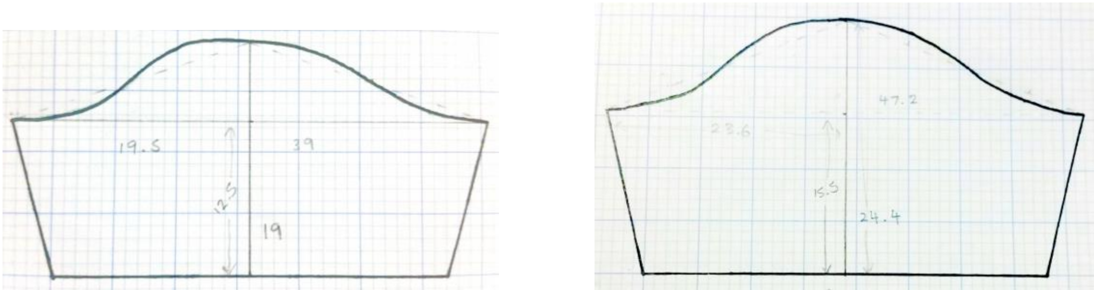
The shirt from which 2D model has been generated, was given to the Participant 01 to fit-on it (Figure 3.33) in order to observe the mismatching and unfitting areas, and to evaluate whether it is similar to the results obtained by comparing the two 2D models. As the first step, the comparison was done using the 2D models of front half of Participant 01 and front half of the shirt (Figure 3.31).



(a) (b)

Figure 3.31. (a) Front half of Participant 01, (b) Front half of Shirt

As the second step, the comparison was done using the 2D models of arm block of Participant 01 and sleeve block of the shirt (Figure 3.32).



(a) (b)

Figure 3.32. (a) Upper arm of Participant 01, (b) Sleeve of the shirt

(a) (b)

Figure 3.33. (a) Front view of Participant 01 wearing the shirt, (b) Side view

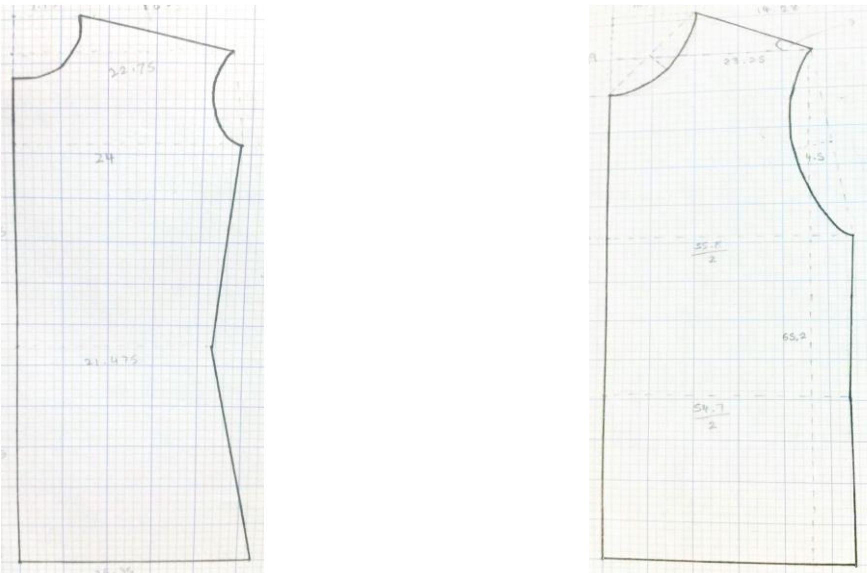
Table 3.25. Comparison of measurements of Participant 01 with the shirt

Participant 01 - Comparison				
Sections	**Calculated value of the Shirt(cm)**	**Measurement of the participant (cm)**	**Difference (cm)**	**Comments regarding Fitness**

Shoulder	25.34	22.64	2.7	Shirt has the correct fit at shoulders
Chest	28.745	28.95	-0.205	Shirt is too small at chest
Hip	27.485	29.125	-1.64	Shirt is too small at hip
Stomach (Waist)	26.225	25.25	0.975	Shirt is tight at stomach
Upper Arm Girth	46.18	39	7.18	Shirt is tight at sleeve
Arm length	25.5	19	6.5	Sleeve length is correct
Length	70.9	69	1.9	Shirt length is correct

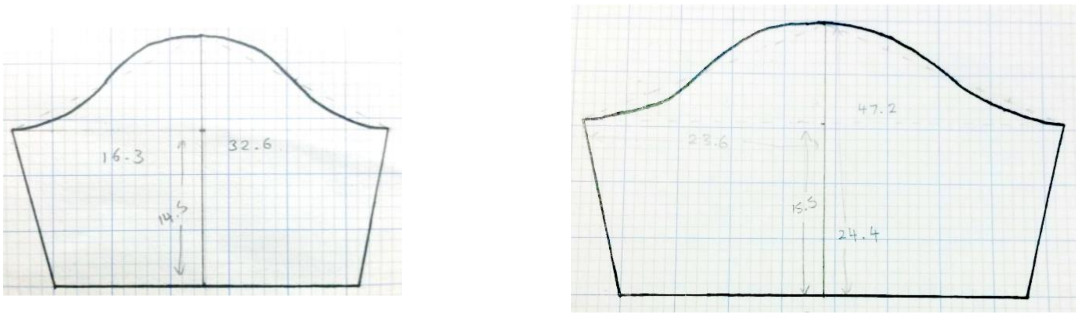
3.4.1.2 Case Study 02

The shirt from which 2D model has been generated, was given to the Participant 02 to fit-on it (Figure 3.36) in order to observe the mismatching and unfitting areas, and to evaluate whether it is similar to the results obtained by comparing the 2D models. Similar to the Case Study 01, first, the comparison was done using the 2D models of front half of Participant 02 and front half of the shirt (Figure 3.34). As the second step, the comparison was done using the 2D models of arm block of Participant 02 and sleeve block of the shirt (Figure 3.35).



(a) (b)

Figure 3.34. (a) Front half of Participant 02, (b) Front half of Shirt



(a) (b)

Figure 3.35. (a) Upper arm of Participant 02, (b) Sleeve of the shirt

(a) (b)

Figure 3.36. (a) Front view of Participant 02 wearing the shirt, (b) Side view

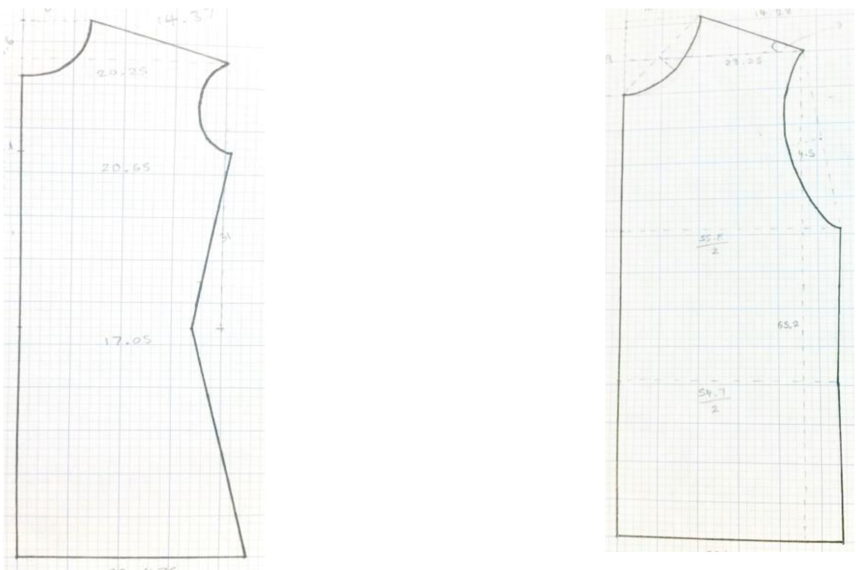
Table 3.26. Comparison of measurements of Participant 02 with the shirt

Participant 02 - Comparison				
Sections	**Calculated value of the Shirt (cm)**	**Measurement of the Participant (cm)**	**Difference (cm)**	**Comments regarding Fitness**

Shoulder	25.34	23.68	1.66	Shirt has the correct fit at shoulders
Chest	28.745	24	4.745	Shirt is loosely fitted at chest
Hip	27.485	27.55	1.135	Shirt has the correct fit at hip
Stomach (Waist)	26.225	21.475	4.75	Shirt has the correct fit at stomach
Upper Arm Girth	46.18	32.6	13.58	Shirt has the correct fit at sleeve
Arm Length	25.5	22.5	3	Sleeve length is larger than the desired sleeve length
Length	70.9	65.8	5.1	Shirt length is correct

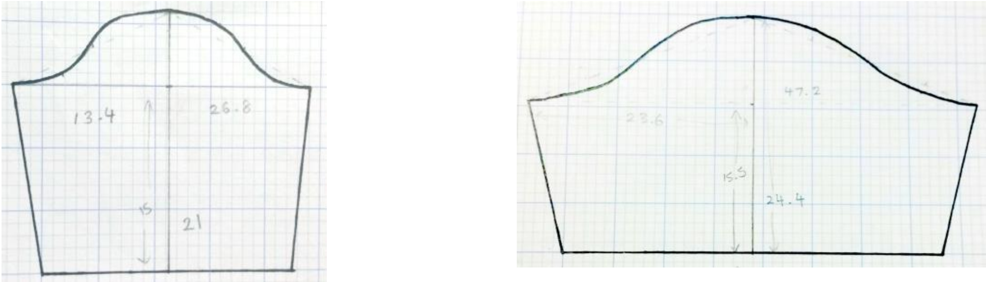
3.4.1.3 Case Study 03

The shirt from which 2D model has been generated, is given to the Participant 03 to fit-on it (Figure 3.39) in order to observe the mismatching and unfitting areas, and to evaluate whether it is similar to the results obtained by comparing the 2D models. Similar to the previous case studies, first, the comparison was done using the 2D models of front half of Participant 03 and front half of the shirt (Figure 3.37). As the second step, the comparison was done using the 2D models of arm block of Participant 03 and sleeve block of the shirt (Figure 3.38).



(a) (b)

Figure 3.37. (a) Front half of Participant 03, (b) Front half of Shirt



(a) (b)

Figure 3.38. (a) Upper arm of Participant 03, (b) Sleeve of the shirt

(a) (b)

Figure 3.39. (a) Front view of Participant 03 wearing the shirt, (b) Side view

Table 3.27. Comparison of measurements of Participant 03 with the shirt

Participant 03 - Comparison				
Sections	**Calculated value of the Shirt (cm)**	**Measurement of the participant (cm)**	**Difference (cm)**	**Comments regarding Fitness**
Shoulder	25.34	21.32	4.02	Shirt is oversized at shoulders

Chest	28.745	20.65	8.095	Shirt is oversized at chest
Hip	27.485	22.475	5.01	Shirt is oversized at hip
Stomach (Waist)	26.225	17.05	9.175	Shirt is oversized at stomach
Upper Arm Girth	46.18	26.8	19.38	Shirt is oversized at sleeve
Arm Length	25.5	21	4.5	Sleeve length is extremely larger than the desired sleeve length
Length	70.9	62.5	8.4	Shirt length is larger than the desired length

3.4.2 Model Comparison - Phase I

When comparing the front block of the garment and the front block pattern of the human upper body, the following areas were considered. Based on the above observations of the experiment, different clothing fitting types such as tight fit, normal fit and comfort fit were defined for these areas.

3.4.2.1 Shoulder Length

The shoulder distance in the shirt was compared with the shoulder distance of human front pattern using the procedure mentioned in the beginning of Section 3.4. By taking the difference between the computed values of shoulder distances of shirt and the human patterns, garment fit at the shoulder was predicted.

Difference = (Shoulder width of the Shirt pattern + Generalized error) –
Shoulder width of the human body pattern

(3.3)

Based on the difference value obtained from the above equation, the shoulder length of the shirt was considered to be shorter/longer than the shoulder length of the user.

3.4.2.2 Shirt Length

The length of the shirt of the front 2D pattern (DH) was compared with the summation of the side neck to waist (KJ) and waist to hip (JO) lengths in the front human body pattern. Here, the length of the human body pattern is equal to the shirt length expected by the user.

Difference of the Length = (Shirt length + Generalized error) - Shirt length expected by the user

(3.4)

Based on the difference value obtained from the above equation, the shirt was considered to be shorter/longer than the expected length by the user.

3.4.2.3 Waist (Stomach)

The waist area measurement of the human body pattern (JG) was compared with the waist area measurement of the 2D pattern of the shirt (IF). We have calculated the difference between the waist measurement of the shirt and the human body. The following comparison criteria was derived based on these difference values.

Difference = (Shirt waist measurement + Generalized error) - Human waist measurement (3.5)

Small: Difference < 0.8

Tight Fit: Difference < 2.0 and Difference >= 0.8

Normal Fit: Difference < 5.0 and Difference >= 2.0

Comfort Fit: Difference < 7.0 and Difference >= 5.0

Oversized garment: Difference >= 7.0

3.4.2.4 Hip

The hip area measurement of the human body pattern (OH) was compared with the hip area measurement of the 2D pattern of the shirt (OG). We have calculated the difference between the hip measurement of the shirt and the human body. The following comparison criteria was derived based on these difference values.

Difference = (Shirt hip measurement + Generalized error) - Human hip Measurement (3.6)

Small: Difference < 0.3

Tight Fit: Difference < 1.2 and Difference >= 0.3

Normal Fit: Difference < 2.0 and Difference >= 1.2

Comfort Fit: Difference < 3.0 and Difference >= 2.0

Oversized garment: Difference >= 3.0

3.4.2.5 Chest

The chest area measurement of the human body pattern (FE) was compared with the chest area measurement of the 2D pattern of the shirt (JE). We have calculated the difference between the chest measurement of the shirt and the human body. The following comparison criteria was derived based on these difference values.

Difference = (Shirt chest measurement + Generalized error) - Human chest measurement **(3.7)**

Small: Difference < 0.5

Tight Fit: Difference < 2.5 and Difference >= 0.5

Normal Fit: Difference < 4.8 and Difference >= 2.5

Comfort Fit: Difference < 6.0 and Difference >= 4.8

Oversized garment: Difference >= 6.0

3.4.3 Model Comparison - Phase II

When comparing the sleeve block of the garment and the sleeve block pattern of the human upper arm the following areas were considered.

3.4.3.1 Upper Arm girth

In here the upper arm girth measurement (CD) of the shirt's sleeve block was compared with the upper arm girth measurement (AC) of the human arm's block pattern. Whenever the AC measurement (cm) is greater than or equal to the CD measurement (cm), the selected shirt was considered to be smaller at the arm area for the particular user. If the AC measurement (cm) is less than the CD measurement (cm), the selected shirt was considered to be suitable at the arm area for the user. Here the suitability was again categorized according to the fitness levels.

Difference = (Arm girth of the shirt + Generalized error) - Arm girth of the human **(3.8)**

Small = Difference < 5.0

Tight fit = 9.0 > Difference >= 5.0

Normal fit = 13.0 > Difference >= 9.0

Comfort fit = 16.0 > Difference >= 13.0

Oversize = Difference > 16.0

3.4.3.2 Upper Arm Length

Here the upper arm length (EL) of the shirt's sleeve block was compared with the upper arm length (BF) of the human arm's block pattern. Whenever the BF measurement (cm) is greater than the

EL measurement (cm), the selected shirt sleeve was considered to be shorter than the user preference of the particular user.

Arm length (human) > Arm length (shirt) =>Sleeve is short

Arm length (human) < = Arm length (shirt) =>Shirt is okay

Chapter 4

Implementation

This chapter elucidates the implementation process and the functions of the prototype system developed according to the design which is discussed in the previous chapter. This chapter first describes about the system which was developed as a prototype, and continues describing the underlying processes of the system.

4.1 Introduction to the System

The system was implemented as a web based application since the proposed solution would serve as an online application in the online marketplace. Since the system was developed as a prototype, the login functionalities were not included in the system. The equations generated through the experiment which was described in the previous chapter were used in the system for the comparison process, and the presentation of the final solution. The system required the measurements of the clothing item and the measurements of the human body as inputs. These inputs were used to model the 2D patterns of the clothing item and the human body in a virtual Cartesian coordinate system. Table 4.1 and Table 4.2 shows the X.Y coordinates of the 2D patterns respectively of front shirt block and sleeve block. Table 4.3 shows the X.Y coordinates of the 2D patterns respectively of front block and arm block of the human body.

Table 4.1. X,Y coordinates of the 2D pattern of the front shirt block

Point	**X coordinate**	**Y Coordinate**
A	0	0
B	0	[Seam Length(g)+f1]/2
C	0	[Seam Length(g) + b1]/2
D	0	Length from middle(g) + f3
E	0	Length from shoulder to hip(g) + f5 + h2
F	[full shoulder width(g) + b1] / 2	length from shoulder to hip(g) + f5
G	[chest(g) + f4]/2	[Seam length(g) + f2]/2
H	[waist(g) + f4]/2	[Seam length(g) + f2]/2
I	[hip(g) + f4]/2	0
J	collar width(g)/2	Length from shoulder to hip(g) + f5 +h1

$$\Theta = cos - 1\{\frac{[full\ shoulder\ width(g)\ +\ b1]\ /\ 2\ -\ [collar\ width(g)\ /\ 2]}{length\ from\ collar\ to\ shoulder(g)}\}$$

h1 = back length from middle(g) - front length from middle(g)

Tan θ = h2/ [full shoulder width(g)/2]

h2 = [full shoulder width(g) / 2] * tanθ

(4.1)

Table 4.2. X,Y coordinates of the 2D pattern of the sleeve block

Point	**X coordinate**	**Y Coordinate**
A	[(Upper arm girth(g) + a1) - (Lower arm girth(g) +a2)] /2	0
B	(Upper arm girth(g) + a1)/2	0

C	[(Upper arm girth(g) + a1)/2]+ [(Lower arm girth(g) +a2)/2]	0
D	(Upper arm girth(g) + a1)	(Under arm length(g) + a3)
E	(Upper arm girth(g) + a1)/2	(Under arm length(g) + a3)
F	0	(Under arm length(g) + a3)
G	(Upper arm girth(g) + a1)/2	(Upper arm length(g) + a4)

Table 4.3. X,Y coordinates of the 2D pattern of the front block of the human body

Point	**X coordinate**	**Y Coordinate**
A	0	0
B	0	Waist to hip(h)
C	0	Waist to hip(h)+ underarm to waist(h)
D	0	[side of the neck to waist(h)+waist to hip(h)]-[(neck girth(h)/6) +0.5]
E	0	Waist to hip(h)+side neck to waist(h)+z
F	(neck girth(h)/6) +0.5	Waist to hip(h)+side neck to waist(h)
G	Neck base width/2	Waist to hip(h)+side shoulder to waist(h)
H	(chest(h)/2 +1)/2	Waist to hip(h)+ underarm to waist(h)
I	(waist(h) /2 +1)/2	Waist to hip(h)
J	(hip(h) /2 +1)/2	0

$$\mathbf{Cos\ \theta = x/FG}$$

$$\theta = \cos^{-1}(x/FG)$$

$$x = \text{neck base width(h)}/2 - [(\text{neck girth(h)}/6)+0.5] \qquad \mathbf{(4.2)}$$

$$\mathbf{Tan\ \theta = EK/x}$$
$$\mathbf{EK = x\ tan\ \theta}$$
$$\boldsymbol{z = EK} \qquad (4.3)$$

The modelled 2D patterns were used to extract several specific measurements which were crucial for the comparison process. The extracted measurements of the clothing item and the human body from their 2D patterns were compared with each other to obtain the difference values. These difference values of measurements were used to provide fit predictions for predefined sections of the body.

The implemented prototype system required two user types. The first user type, ‘Vendor’ was provided the ability to add clothing item information to the database of the system. Since the scope of the system was limited to men’s short-sleeves shirts the system only contained the functionalities to add information regarding men’s short-sleeves shirts. There, the system demands for the measurements which were specific for men’s short-sleeves shirts from the vendor. The second user type, ‘Buyer’ was given the capability of inserting his/her own measurements to the system and check the fit of a particular clothing item that has already been available in the system. The developed prototype system contained the ability to cater only males since the design was experimented and finalized for males. The following sections of this chapter discuss further about the implemented prototype system thoroughly.

4.2 Main View of the System

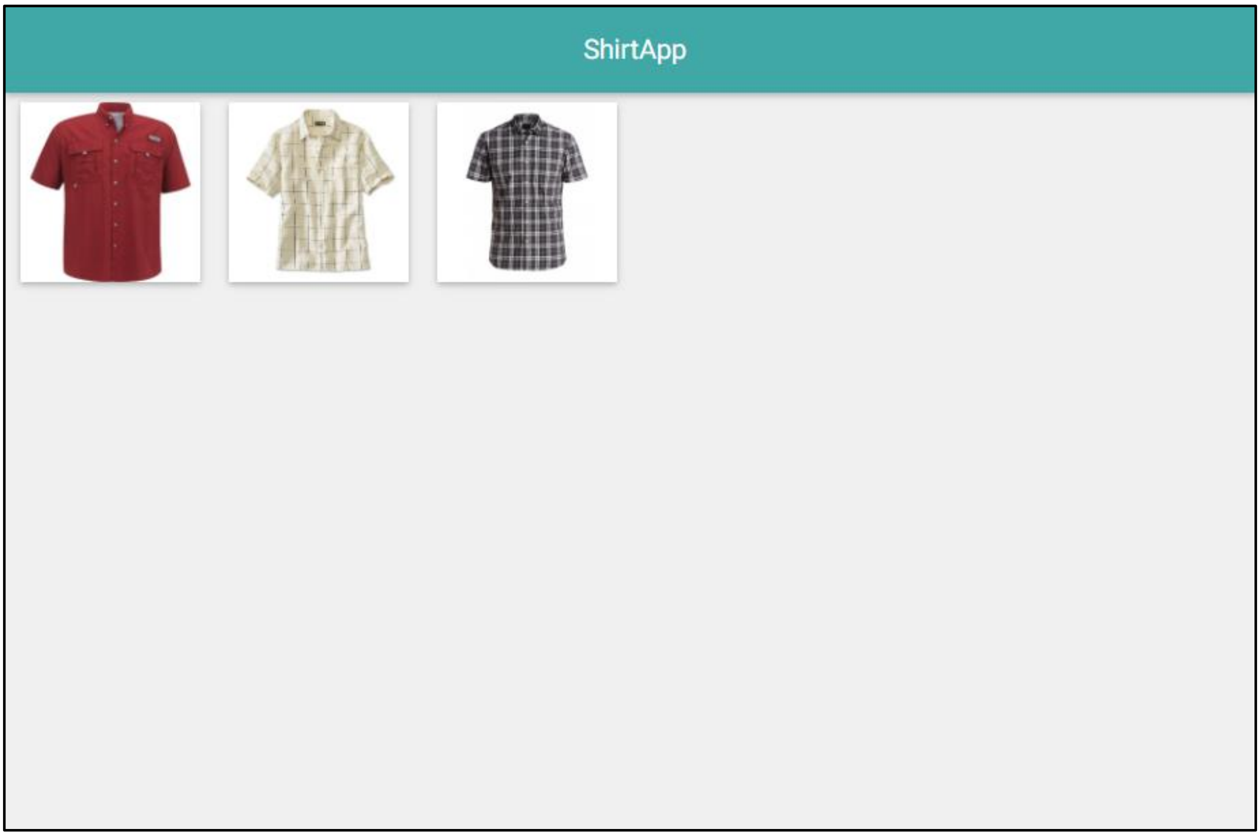


Figure 4.1. Main view/ home page of the system

The main view of the prototype remains as common for both vendor and buyer. This view displays the available clothing items of the online store using images as shown in Figure 4.1. When a new clothing item is added to the system, this view is updated and the new clothing item is displayed.

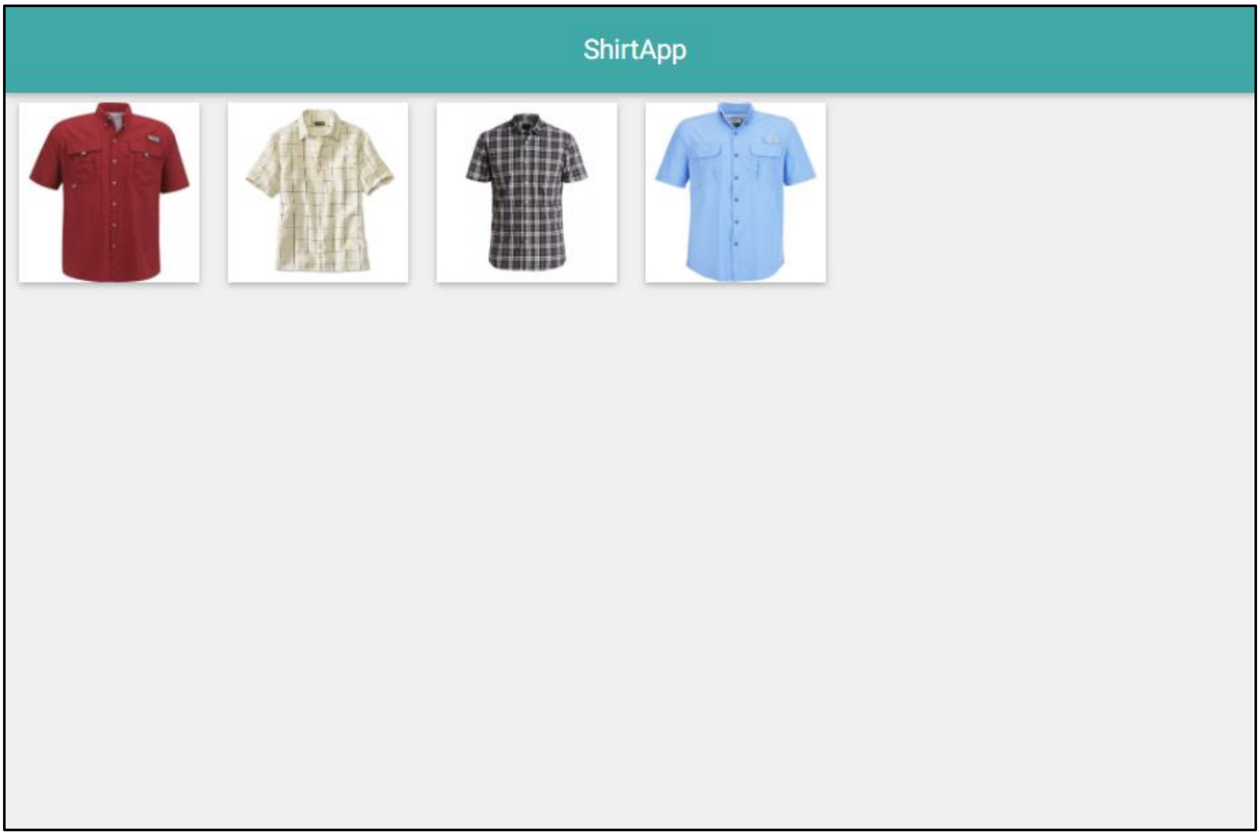


Figure 4.2. Updated view of the homepage of the system

The vendor is provided the capability of adding the image of a new clothing item when entering details of that particular clothing item to the system. The process of adding clothing items to the system is discussed in the following section.

4.3 Functionalities of the Vendor

The main task of a vendor is to add clothing items to the system. When adding clothing item details to the system, the vendor only has to add the measurements of a particular size of the clothing item. The system was initially developed for men's short sleeves shirt. Men's short sleeves shirts consist of several different sizes. In order to add a new short sleeves shirt item that contained variety of sizes to the system, the vendors have to pick one shirt size and measure only one shirt. The measurements that has shown in Figure 4.3, 4.4 and 4.5 are the inputs for a short sleeves shirt.

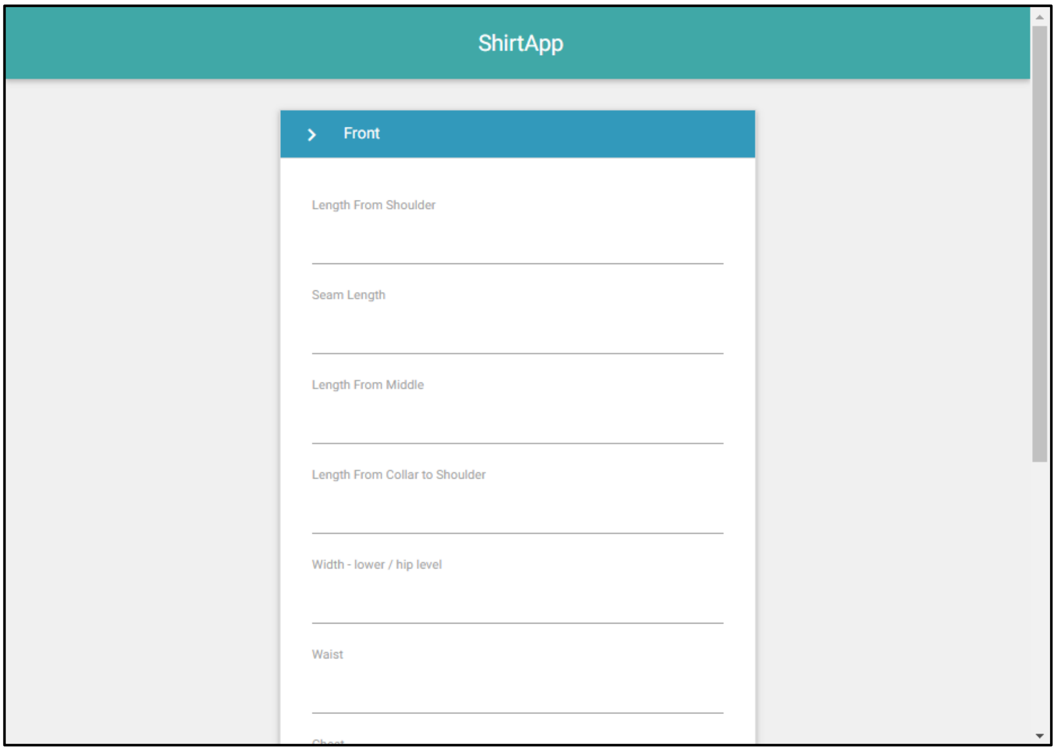


Figure 4.3. Measurements to be taken from the front side of the shirt

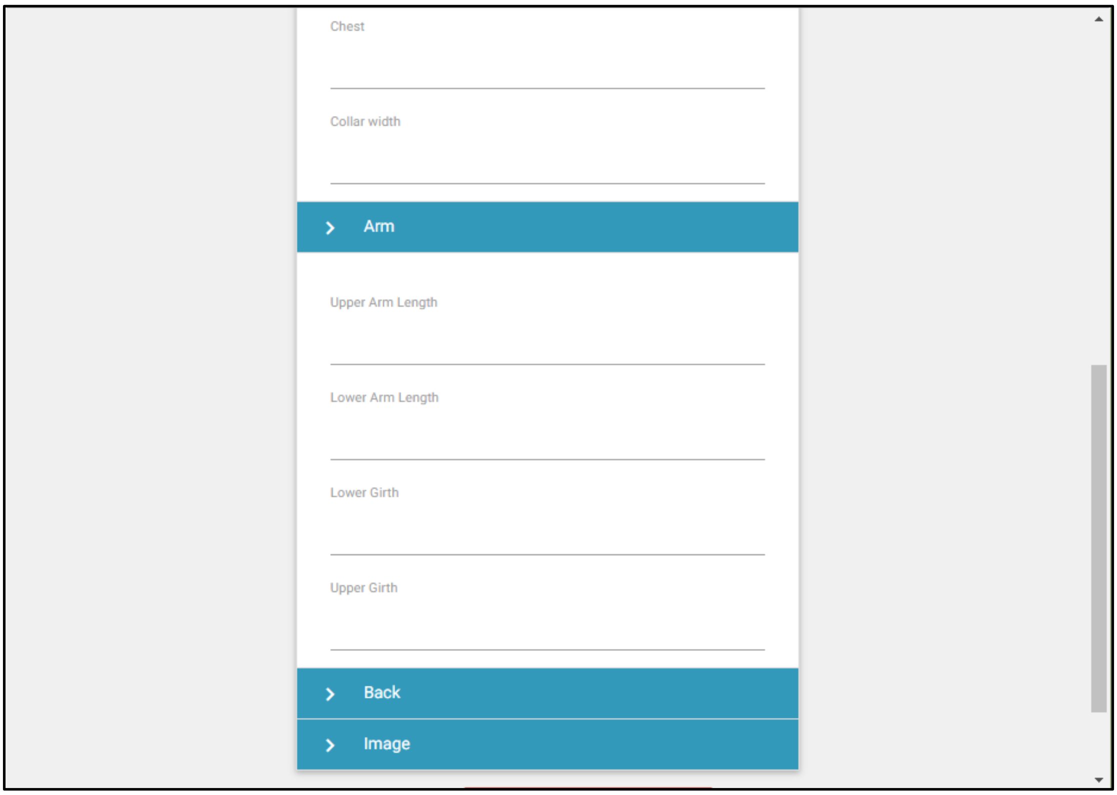


Figure 4.4. Measurements to be taken from the sleeve of the shirt

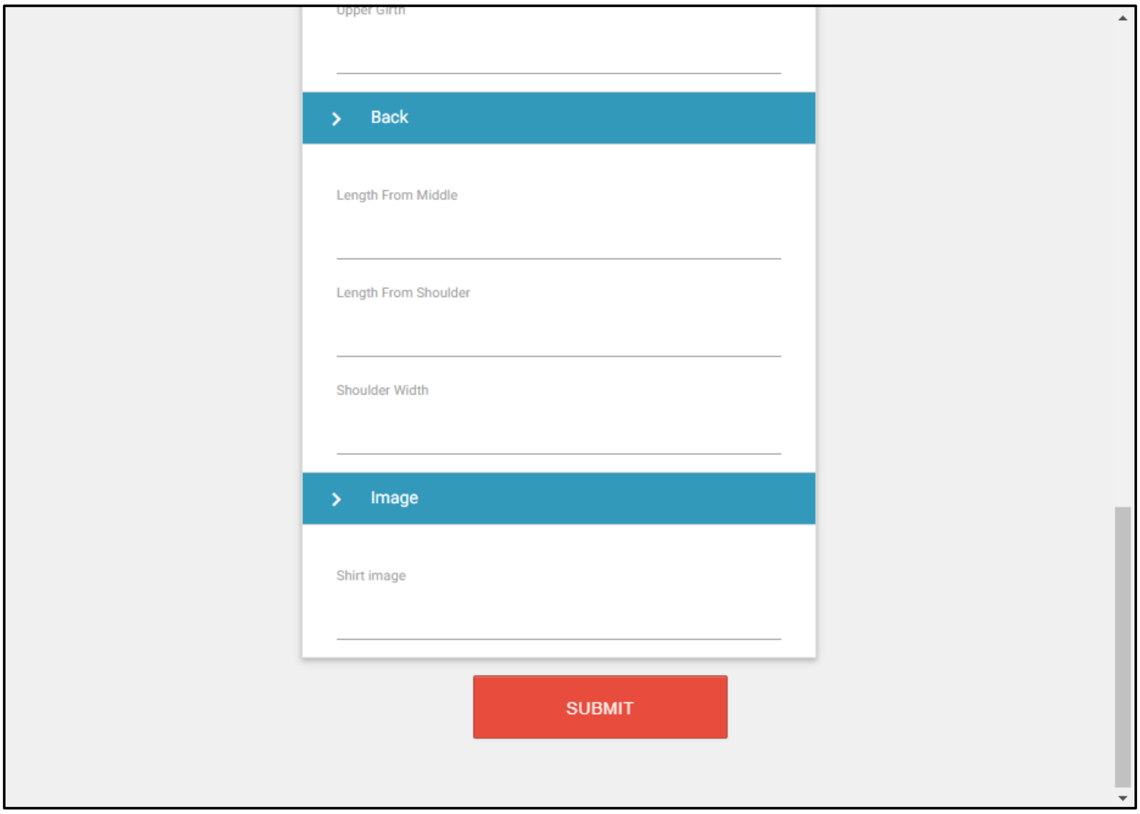


Figure 4.5. Measurements to be taken from the back side of the shirt

4.4 Functionalities of the Buyer

The buyer's functionalities was designed to input the measurements required by the system as the first step. The required measurements of the buyer are shown in Figure 4.6 (a), Figure 4.7 (b) and Figure 4.8 (c). The system provides the information on taking the measurements of the body using referring images, resulting in easy identification of the measuring locations of the human body.

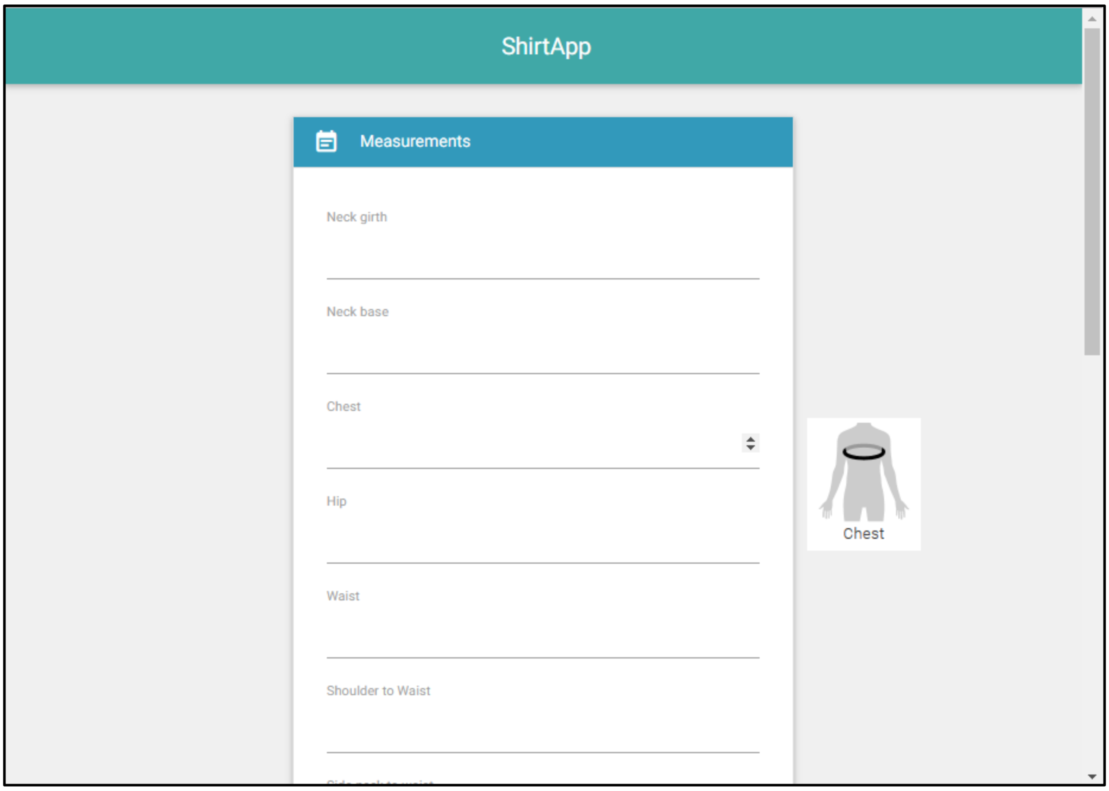


Figure 4.6. (a) Measurements required from the buyer

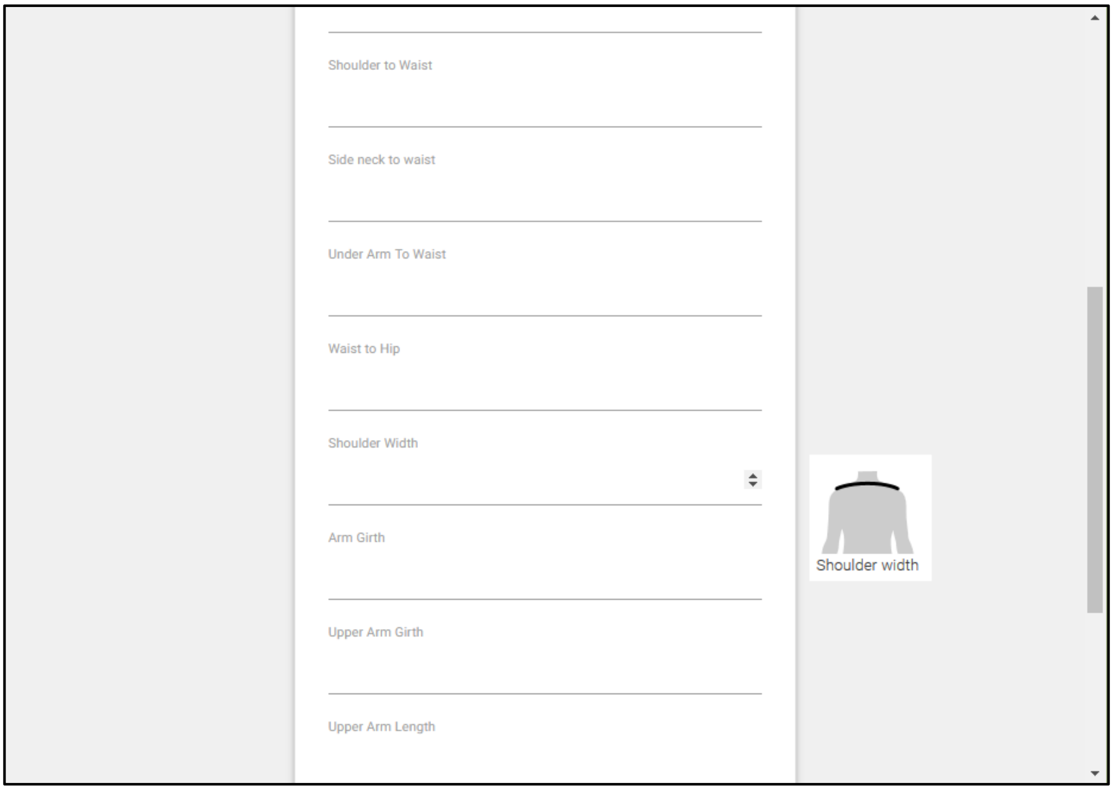


Figure 4.7. (b) Measurements required from the buyer

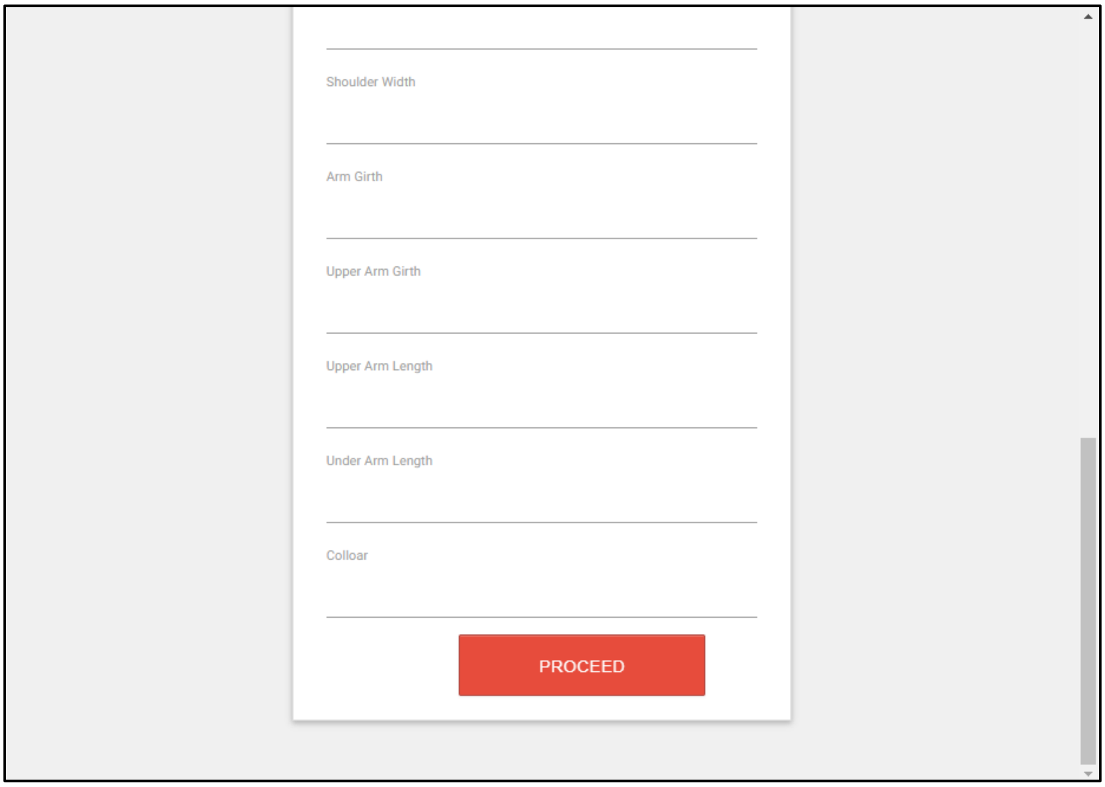


Figure 4.8. (c) Measurements required from the buyer

When the buyer proceeds after providing all the necessary measurement values, then the buyer has to input the fitting preference. There are three types of fitting preferences from which a buyer can select from; slim fit, normal fit and tight fit.

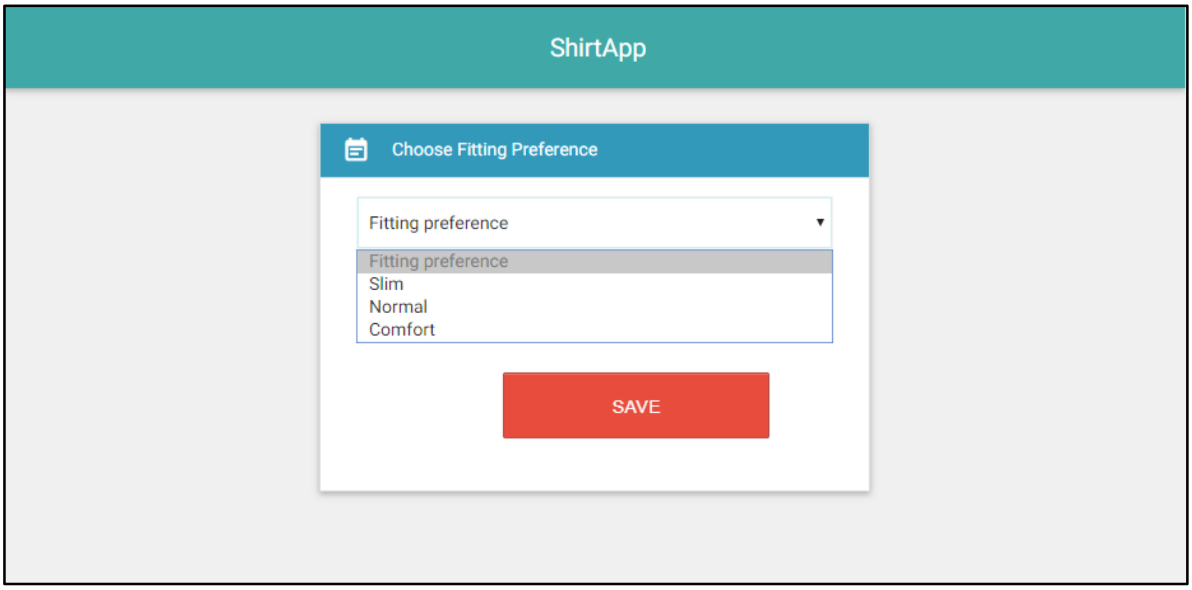


Figure 4.9. Fitting preferences of a buyer

After saving the entered inputs, the buyer is redirected to the home page of the system. As the next step, the buyer can select a clothing item displayed in the home page. Afterwards the buyer would get a detailed visual representation of the garment fit.

4.5 Visual Representation of the Garment Fit

Selecting a suitable and satisfactory visual representation of garment fit was one of the research questions that were addressed through this research study. An image of a shirt was created using SVG graphics. The shirt was divided into several sections such as chest, waist, hip and arms. When the required measurements are entered to the system and the buyer selects a particular shirt, each section of the image gets filled with a colour that corresponds to a predefined fitting level. These colours also correspond to the heat map colours. Red colour depicts that the shirt is too small at that specific area for the user. Yellow colour depicts that the shirt is tight at that specific area for the user. Green colour depicts that the shirt is fitting perfectly at that specific area for the user. Light blue colour depicts that the shirt is loose at that specific area whereas Dark blue colour depicts that the shirt is too large at that specific area. When the system was first implemented and tested using a data set the following result was obtained (Figure 4.10).

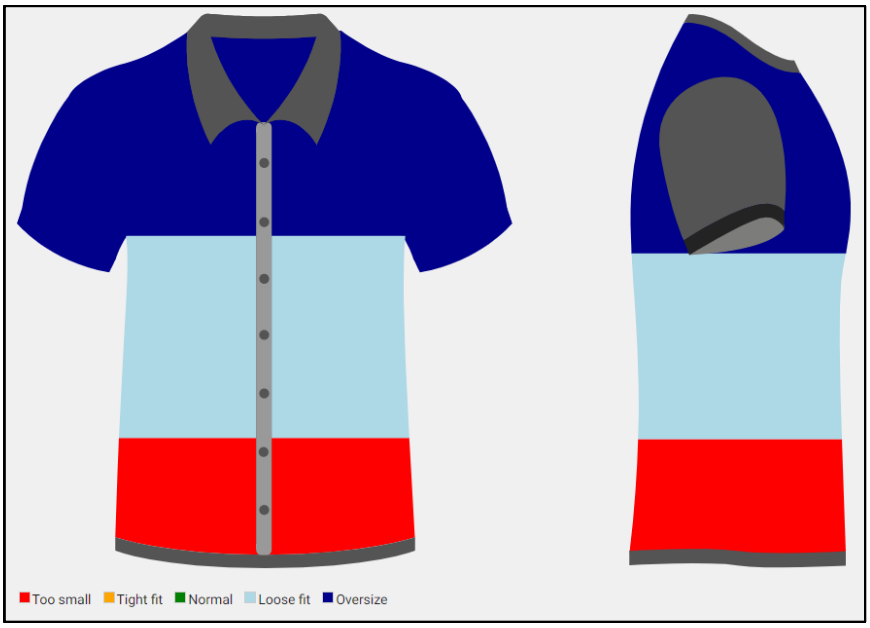


Figure 4.10. Results of the first iteration

After conducting several focus group discussions, some problems were identified regarding this representation of the garment fit. Since the sections were filled with the colours, the users were unable to comprehend what the image displaying. Another problem with this representation was, the sections were separated by sharp edges. When a garment is worn, the garment fit varies from one place to another. For example, if a garment is tight at the chest area, the tightness might be less below the chest area resulting in gradually lessen the tightness from one area to another. But, according the results obtained from the first iteration of the implementation, the garment fit was not depicted as intended. In order to provide a better representation of garment fit to the users, colour gradients were used. Figure 4.11 shows the result obtained after the use of colour gradients on the image.

Figure 4.11. Results of the second iteration

With the visualization of the fitness of the garment, the system was designed to provide the fitness of the garment in written format as shown in Figure 4.12. There, the fitness was presented with respect to the specified seven areas. The arm length and shirt length was depicted in a different format in order to enhance the understanding of the user. The computed difference values at arm length and shirt length were presented as shown in Figure 4.12. For example, if the shirt length was 5 cm longer than the expected shirt length of the user, the system represent it as “5 cm longer than expected length”.

Stomach	Oversized
Arm Length	3cm longer than expected length
Arm Girth	Oversized
Hip	Oversized
Shoulder	Oversized
Shirt Length	5cm longer than expected length
Chest	Oversized

Figure 4.12. Visualization of fitness in written format - first iteration

After the first iteration, several group discussions were carried out in order to improvise the visual representation of the system. It was identified that the representation of the written results could be modified into a more user friendly format as a result of the group discussions carried out. As a result, the visualization of the fitness which was in a written format was modified by presenting the outputs in a tabular format as shown in Figure 4.13 for better identification of the fitness results.

Figure 4.13. Visualization of fitness in written format after second iteration

Area	Fitness Level
Stomach	Tight
Arm Length	7cm longer than expected length
Arm Girth	Oversized
Hip	Too Small
Shoulder	Oversized
Shirt Length	NaNcm. A perfect match
Chest	Too Small

4.6 System Requirements of Implemented Prototype

The system which is implemented based on the proposed methodology could be operated with low processing power due to its nature of rendering a 2D solution. The system has been operated successfully on an operating system with the requirements specified in the Table 4.4.

Table 4.4. Assessed system requirements of the implemented system

Operating system	Windows 7 or any other superior version
CPU	Intel(R) Core(TM) i3-4010U CPU at 1.70 GHz or higher
Memory	4 GB RAM

The aforementioned requirements could be considered as the minimum requirements on which the operation of the system has been assessed. The final result of the system could be obtained within few seconds when the system is executed in a machine with requirements specified in the Table 4.4, which could be considered as a negligible time. The system could not be assessed in a machine with low processing power compared to the aforementioned requirements in the Table 4.4 due to the low usage of such operating systems.

Chapter 5

Results and Evaluation

5.1 System Results

The implemented system was used to analyse the garment fit of three short sleeve men's shirts which have collar sizes of 15 inches, 15.5 inches and 16 inches on a set of male participants who are in the age category of 23-27 years. The required measurements were extracted from these three shirts to be used as inputs to the system (Table 5.1). Moreover 20 male participants were selected to obtain outputs from the implemented system. Apart from the measurements of the three shirts, upper body measurements and fitting preferences of the sample of 20 participants were also extracted to be used as inputs to the system (Table 5.2). Each participant was asked to select a shirt from the given three shirts. The extracted body measurements of the participants and the measurements of the corresponding shirt they have selected were input to the system in order to obtain the shirt fitness for each participant via the system. After performing the system calculations, the fitness of the selected shirt for the respective participant/system user was visualized by the system (Figure 5.1 and Figure 5.2).

Table 5.1. Measurements of the shirts

	Measurement	**Value (cm)**		
		Shirt 01	Shirt 02	Shirt 03
	Front Measurements			
1.	Length from Shoulder	60.2	62.2	65.2
2.	Length from Middle	57.6	58.4	59.5
3.	Seam Length	36.2	39.8	41.7
4.	Width from Hip Level	49.2	51	54
5.	Width from Waist Level	48.7	52.2	52.2
6.	Width from Chest Level	48.6	52	53
7.	Collar Width	14.6	14.5	15
	Back Measurements			
8.	Length from Middle	64.5	65.8	71.5
9.	Length from Shoulder	59.9	61.6	65.9
10.	Shoulder Width	44.7	43	47.4
11.	Length from Collar to Shoulder	15.5	14.2	17.5
	Sleeve Measurements			
12.	Upper Arm Length	22.3	21.7	24.2
13.	Under Arm Length	15	11.3	14.1
14.	Lower Girth	36.2	34	36.4
15.	Upper Girth	46.6	40.6	45.4

Table 5.2. Body Measurements and fitting preference of the sample user set

Users	Measurements												
	Neck girth	Neck based width	Chest	Hip	Waist	Side shoulder to waist	Side neck to waist	Underarm to waist	Waist to hip	Shoulder width	Upper arm length	Upper arm girth	Arm hole	Fitting preference
User 01	38.5	39	101.8	98.5	82	33	40	23	30	42.5	22	35.4	45	Slim fit
User 02	40	42	98.5	104	87.7	32.5	37.5	20.5	25	43	23.5	31.5	41.7	Slim Fit
User 03	36.5	39	86	92.5	73.2	32	38	22.5	25	44	21	31	40.5	Normal
User 04	38	40	98	94.3	72.3	31	39	21	24	44	25.5	30	42	Normal
User 05	40	41	103	106	94.7	31	40	19	28	49.5	24	37.5	45	Normal
User 06	35	40.8	96.5	94.8	84.8	39	40	21	29	42.3	21	29.8	43	Slim fit
User 07	37	40.5	80.6	87.9	66.2	31	35.5	20.5	27	40.2	21	26.8	37.5	Normal
User 08	39.8	45.5	94	103.4	83.9	34	38.5	23.5	27.3	46.4	22.5	32.6	38.7	Normal
User 09	40	42.7	113.8	114.5	99	36	41	16.5	28	46.8	19	39	50.3	Slim fit
User 10	42	47.5	108	104.5	92.7	31.5	39.5	18	31	50	25	37.7	49.5	Normal
User 11	37.7	43	93	97.5	84.5	32.5	40	18	28.5	47	23	33.5	48.5	Normal
User 12	40.5	44	101.5	106	88	35.5	41.5	20	26	48	25.5	34	50.5	Slim fit
User 13	36	39.5	85	93	74.5	29	37.5	18	23.5	42	22.5	29.5	41	Normal
User 14	39	44	91	97	80.5	30	38.5	18.5	31	47	23	35	44	Normal
User 15	38.5	44	95	106	86.5	33.5	41.5	17	23	47.5	25.5	35.5	50	Slim fit
User 16	37.5	43	90.5	100	82.5	32	38.5	18.5	25.5	46	23	32	46.5	Slim fit
User 17	35.5	40	72.5	85	62	34	39.5	22	22	43.5	22.5	22.5	38	Slim fit
User 18	40	41	100	102	88.7	33.5	38.5	21.5	26	44	24.5	32.5	42.7	Normal
User 19	41.5	43	100.5	105	89	36.5	42.5	22	25	47	24.5	33	49.5	Normal
User 20	41	42	100	95.3	73.3	32	39	22	25	45	25.5	31	42	Normal

Figure 5.1(a) and Figure 5.2(b) shows the results obtained via the system for user 10. The measurements of Shirt 03 were used for this comparison. The garment fit was represented in two formats; using an image and using a tabular format. Figure 5.1(a) shows the visualization provided as an image for user 10. An image of a short sleeve shirt was used to represent garment fit. The shirt image is divided into four areas namely, chest area, stomach area, hip area and sleeves. According to Figure 5.1(a), the garment is too small for user 10 at his chest area, which is shown in red colour. Moreover, the garment has a normal fit at his stomach area while the garment is tight at his hip area and sleeves. Presenting the garment fit in a tabular format was another way to display garment fit in our proposed solution. Figure 5.2(b) shows a more detailed description regarding the garment fit for user 10. This tabular format

displays garment fit with regard to shoulder length, shirt length and sleeve length apart from the garment fit at chest, stomach, hip and sleeve.

Figure 5.1. (a) Results obtained from the system for user 10

Area	Fitness Level
Stomach	Normal
Sleeve Length	3.20cm longer than expected length
Sleeve Tightness	Tight
Hip	Tight
Shoulder	2.2cm longer than expected length
Shirt Length	3cm longer than expected length
Chest	Too Small

Figure 5.2. (b) Results obtained from the system for user 10

5.2 Evaluation of the Results

Elucidation of the accuracy of the suggested solution was done by adopting two main approaches of qualitative evaluation. Under first approach of qualitative evaluation, the results of the system were directly compared with the photographs of the human users wearing respective shirts.

Under the second approach of qualitative evaluation, available 3D garment fitting applications were used. Marvelous Designer 7 and CLO3D were selected as the 3D commercial software tools for the second approach of the evaluation.

5.2.1 Qualitative Evaluation – Approach 1

The aforementioned 20 participants were engaged in this qualitative evaluation process as well. First, each participant was asked to wear the short sleeve shirt that they have selected (which was used to obtain system outputs). After that, photographs of those participants wearing the respective shirts were captured. The photographs were captured from two angles as represented below.

(a) (b)

Figure 5.3. Participant wearing the selected shirt (a) Front view (b) Side view

The shoulder length, chest area, stomach area, hip area, shirt length, sleeve length and arm tightness at sleeve were the main seven sections that were observed from these user images. The subjectivity of the observations were reduced by engaging only one observer for this qualitative evaluation. Garment fit at each of these sections except shoulder, shirt length and sleeve length was identified and then assigned to predetermined fitting categories/types. These fitting categories include 'too small', 'tight fit', 'normal fit', 'loose fit' and 'oversize'. For example, if the garment fit at the chest area was identified to be extremely tight for a particular participant, then the garment fit at chest area was assigned to the 'too small' category for that participant. Garment fit observed with respect to the shoulder was assigned to three categories such as 'Perfect match', 'Too large' and 'Too small'. The categorization for the evaluation was done using the same set of participants of the evaluation. Participants were questioned about their preferred shoulder length and upto what extent it was considered to be perfect match. With the results gained, it was clarified that the Perfect match of a shoulder length was considered when the actual shoulder length of the users were completely matched with the shoulder length of the selected shirt (0 difference) or the difference taken upto 2.5cm. The shoulder length was considered as too large when the difference between actual shoulder length of users and the shoulder length of the selected shirt was above 2.5cm whereas too short was reviewed when the shoulder length of the selected shirt was less than users shoulder length. The observations of the captured photographs were then compared with the system results (system outputs) obtained via the implemented system for each participant with respect to shoulder length, chest area, stomach area, hip area and sleeve tightness. Garment fit with respect to sleeve length and shirt length were not observed using the photographs since the human inputs corresponding to these measurements were obtained as the sleeve length and shirt length that the users have expected. Thus, the feedback of the participants were obtained with respect to sleeve length and shirt length of the shirt they wore. These feedbacks were categorized into three main feedbacks ('Perfect length', 'Too long' and 'Too short'). These three areas were clarified clearly according to the answers given by the participants in the evaluation process. According to that the Perfect length was taken as the difference between users preferred length and the selected shirt length which was identified as 0 difference to difference up to 2.5cm. Too short was taken when the selected shirt length was less than users preferred length whereas Too long indicated the selected shirt length was higher than the users preferred length.

Using this comparison, the accuracy of the suggested solution (Implemented system) was determined, which is described in the latter part of this chapter (Figure 5.7, Figure 5.8, Figure 5.9, Figure 5.10, Figure 5.11, Figure 5.12, Figure 5.13 and Figure 5.14).

5.2.2 Qualitative Evaluation – Approach 2

After the first approach of the qualitative evaluation of the suggested solution (the implemented system), another qualitative evaluation was conducted using the same user sample (20 participants). The cloth manufacturing industry uses commercial software products to undertake virtual garment fitting. The commercial software products utilizes the 3D avatar models and 3D clothing models to analyze the garment fit against a virtual human body. Marvellous Designer 7 and CLO3D were selected and used for the evaluation of our research. 3D human body meshes were constructed for all 20 participants of the study using CLO3D software, by customizing the available generic body mesh using the measurements of the participants. 3D models of the aforementioned three short sleeves shirts were also constructed using Marvelous Designer software. The short sleeve shirt model which is available in the Marvelous Designer software was manipulated in order to construct the required shirts. The block pattern of the available shirt model was customized using the measurements of each shirt in order to construct the aforementioned short sleeves shirts.

The constructed 3D mesh models of the participants were then imported to the Marvelous Designer software. Then the corresponding mesh of the shirt was superimposed on the human body mesh of each participant (Figure 5.3). For an instance, if a participant selected a shirt with the collar size of 16 inches, then the mesh model of the shirt with the collar size of 16 inches was superimposed and simulated on the human body mesh model of that participant. During this process we had to use both CLO3D since customisation of available human and garment meshes is not facilitated through Marvelous Designer thus we had to generate the customized meshes from CLO3D and import them to Marvelous Designer. A strain maps were generated for all 20 instances. Using the strain map, the fitness of the selected shirt for the each particular user was interpreted. The strain map depicts the pressure (kPa) upon the material that is draped upon a human body model. If the pressure of the material at a certain human body area is between 100% and 110%, the corresponding area of the model is represented in green colour which indicates that the garment material is neither in a stretched nor in a compressed-state. If the pressure of the material at a certain human body area is between 110% and 120%, the corresponding area of the model is represented in yellow-orange colour which indicates that the garment material is in a semi-stretched state. If the pressure of the material at a certain human body area is between 120% and 130%, the corresponding area of the model is represented in red colour which indicates that the garment material is in a fully stretched state (Figure 5.5).

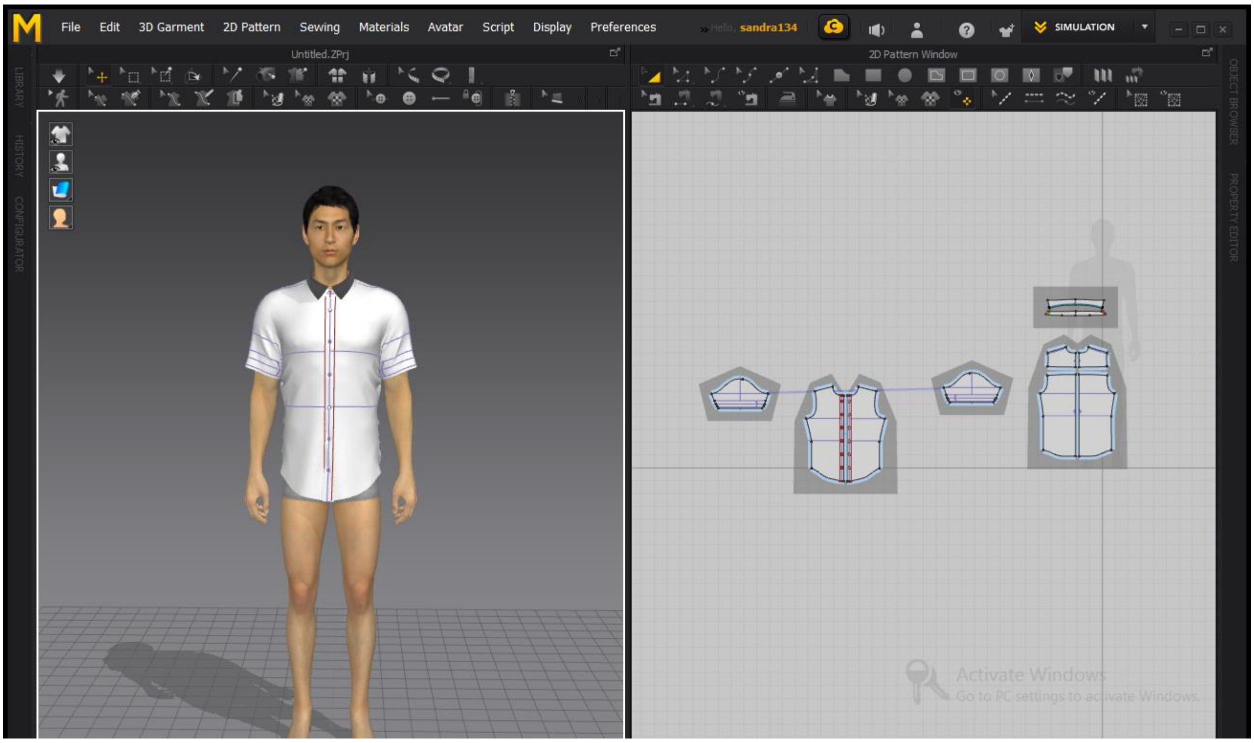


Figure 5.4. Simulating the 3D model of the shirt on a 3D model of a human body

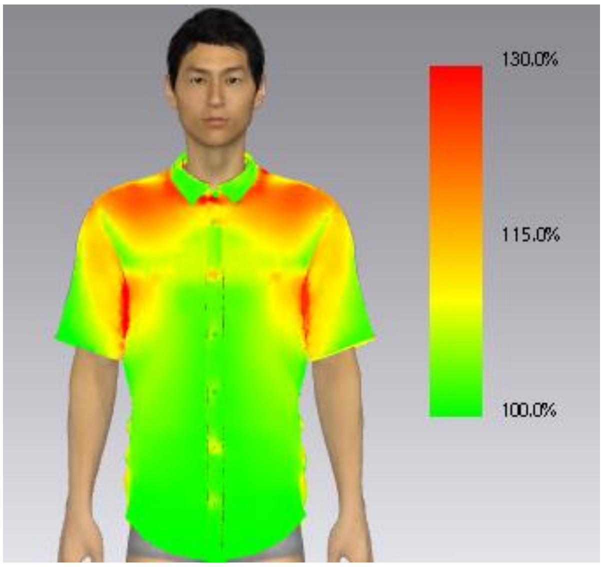


Figure 5.5. Representing the garment fit using the strain map

The initial idea was to compare the strain maps generated for each user through Marvelous Designer with the results of the implemented system. Later we realized that it is not reasonable to compare our solution directly with the solution provided by the commercial software since both solutions do not provide perfect results regarding the fitness of a specific garment to a particular individual. Generally people determine the fitness of a particular garment by wearing it and checking the appearance from a mirror. It concludes that the fitness of a particular garment is quantified based on the appearance and the decision of purchasing the garment is made based on the appearance thus in the context of real world the decision taken based on the real appearance of the person after fitting the garment, is considered as the most correct fitness. In this research we have observed the fitness of short sleeve shirts to the users in the real environment and we have taken the aforementioned fitness in the real environment, which is the fitness measured from the human eye, as the most correct fitness. Moreover we have deduced the fitness using Marvelous Designer and the system which is implemented according to the methodology proposed by this research. We have compared the fitness results obtained through the Marvelous Designer and the outcomes of the implemented system against the values taken by observing the real users. We have compared the accuracy rate of the implemented system through a qualitative evaluation of the results obtained by the aforesaid comparison between real users against commercial software and real users against the implemented system.

5.2.3 Analysis of Evaluation

The results of both implemented system and commercial software have been compared with fitness values obtained by observing the real users since the fitness of a particular shirt is most accurately rationalized using the real users. Here, the garment fit at the most problematic areas when wearing a short sleeves shirt was analyzed (Shoulder, chest, stomach, hip, shirt length, sleeve length and sleeve tightness). In the following tables, the first column shows the list of users engaged in the study, and the second column represents the garment fit observed from real users who are wearing the shirts. The third column displays the results provided for each user by the implemented system. The fourth column shows the results obtained from the commercial software used for each user. The fifth column contains the comparison between the actual garment fit (Real) and the results provided the implemented system. The sixth column of the following tables consists of the comparison between the actual garment fit and the results obtained from the commercial software.

Figure 5.6. Comparison of natural human observations with implemented system and commercial software

The comparison was conducted by following a logical approach in which True or False are specified as the outcomes of the comparison. The comparison result was interpreted as True if the implemented system provided results resemble to fitness observed from the real users. On the contrary, if there were deviations in the results provided by the implemented system compared to the real user fitness, it was interpreted as False. The same procedure was applied for the comparison in between the results of the real users and commercial software apart for the shirt length and sleeve length hence those two areas were not indicated through commercial software.

5.2.3.1 Shoulder length

Table 5.3. Comparison of natural human observations with implemented system and commercial software at shoulder area

	Results through natural human observation	Results of implemented system	Results of commercial Software	Natural vs. Implemented System Comparison	Natural vs. Commercial Software Comparison
User 01	Perfect fit	Perfect fit	Perfect fit	True	True
User 02	Too large	Perfect fit	Perfect fit	False	True
User 03	Too large	Perfect fit	Too large	False	True
User 04	Perfect fit	Too large	Perfect fit	False	True
User 05	Too large	Too large	Too large	True	True
User 06	Perfect fit	Perfect fit	Perfect fit	True	True
User 07	Too large	Too large	Too large	True	True
User 08	Perfect fit	Perfect fit	Perfect fit	True	True
User 09	Perfect fit	Too large	Too small	False	False
User 10	Perfect fit	Perfect fit	Perfect fit	True	True
User 11	Perfect fit	Perfect fit	Perfect fit	True	True
User 12	Too large	Too large	Perfect fit	True	False
User 13	Too large	Too large	Too large	True	True
User 14	Perfect fit	Perfect fit	Perfect fit	True	True
User 15	Too large	Too large	Too large	True	True
User 16	Perfect fit	Perfect fit	Perfect fit	True	True
User 17	Too large	Too large	Too large	True	True
User 18	Too large	Too large	Too large	True	True

User 19	Too large	Too large	Too large	True	True
User 20	Too large	Too large	Too large	True	True

According to the comparison of implemented system results and commercial software results with real user results, the accuracy for the shoulder length was identified as follows.

From the comparison of actual user results with implemented system results,

Implemented System Accuracy = $\frac{No.\ of\ "True"\ results}{No.\ of\ all\ results} \times 100\%$ **= 80%**

No. of ‘True’ results: Total number of ‘True’ responses obtained from the comparison between the implemented system and the observation of the photographs of real users regarding the fitness of Shoulder Length

No. of all results: Total number of responses obtained from the comparison between the implemented system and the observation of the photographs of real users regarding the fitness of Shoulder Length

From the comparison of actual user results with commercial software results,

Commercial Software Accuracy = $\frac{No.\ of\ "True"\ results}{No.\ of\ all\ results} \times 100\%$ **= 90%**

No. of ‘True’ results: Total number of ‘True’ responses obtained from the comparison between the commercial software and the observation of the photographs of real users regarding the fitness of Shoulder Length

No. of all results: Total number of responses obtained from the comparison between the commercial software and the observation of the photographs of real users regarding the fitness of Shoulder Length

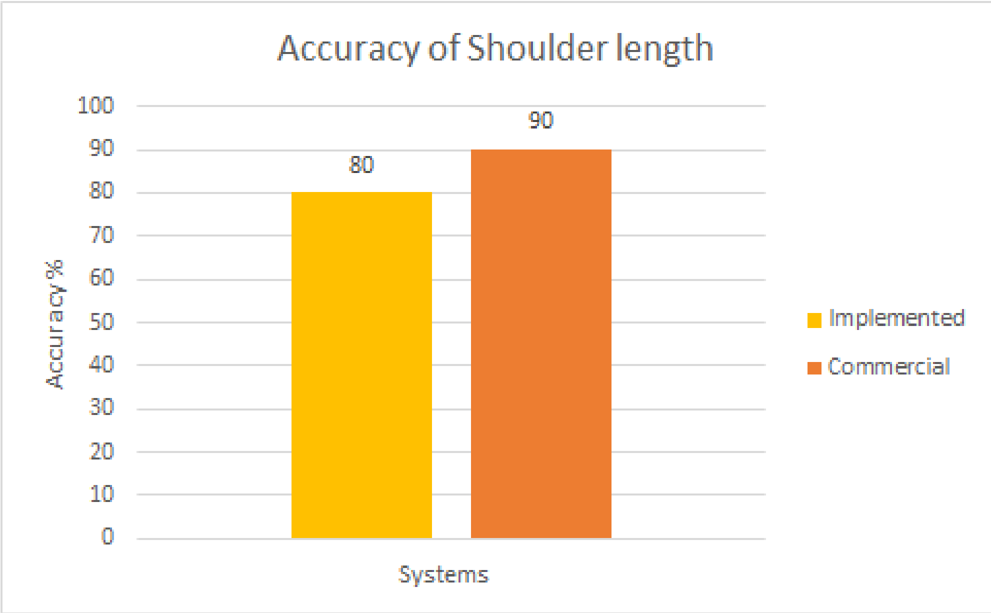


Figure 5.7. Comparison of implemented system accuracy with commercial software accuracy at shoulder length

5.2.3.2 Chest area

Table 5.4. Comparison of natural human observations with implemented system and commercial software at chest area

	Results through natural human observation	Results of implemented system	Results of commercial Software	Natural vs. Implemented System Comparison	Natural vs. Commercial Software Comparison
User 01	Tight fit	Tight fit	Tight fit	True	True
User 02	Normal fit	Normal fit	Normal/ Loose fit/ Oversize	True	True
User 03	Loose fit	Loose fit	Normal/ Loose fit/ Oversize	True	True
User 04	Loose fit	Normal fit	Normal/ Loose fit/ Oversize	False	True
User 05	Normal fit	Normal fit	Normal/ Loose fit/ Oversize	True	True
User 06	Normal fit	Normal fit	Tight fit	True	False
User 07	Loose fit	Loose fit	Normal/ Loose fit/ Oversize	True	True
User 08	Normal fit	Normal fit	Tight fit	True	False
User 09	Too small	Too small	Too small	True	True
User 10	Tight fit	Tight fit	Tight fit	True	True

User 11	Normal fit	Loose fit	Normal/ Loose fit/ Oversize	False	True
User 12	Normal fit	Normal fit	Normal/ Loose fit/ Oversize	True	True
User 13	Loose fit	Loose fit	Normal/ Loose fit/ Oversize	True	True
User 14	Tight fit	Loose fit	Tight fit	False	True
User 15	Normal fit	Normal fit	Normal/ Loose fit/ Oversize	True	True
User 16	Normal fit	Normal fit	Normal/ Loose fit/ Oversize	True	True
User 17	Oversize	Oversize	Normal/ Loose fit/ Oversize	True	True
User 18	Tight fit	Too small	Tight fit	False	True
User 19	Normal fit	Normal fit	Normal/ Loose fit/ Oversize	True	True
User 20	Normal fit	Loose fit	Normal/ Loose fit/ Oversize	False	True

According to the comparison of the implemented system results and commercial software results with real user results, the accuracy for the chest area was identified as follows.

From the comparison of actual user results with implemented system results,

Implemented System Accuracy = $\frac{No.\ of\ "True"\ results}{No.\ of\ all\ results} \times 100\%$ = **75%**

No. of ‘True’ results: Total number of ‘True’ responses obtained from the comparison between the implemented system and the observation of the photographs of real users regarding the fitness of Chest area

No. of all results: Total number of responses obtained from the comparison between the implemented system and the observation of the photographs of real users regarding the fitness of Chest area

From the comparison of actual user results with commercial software results,

Commercial Software Accuracy = $\frac{No.\ of\ "True"\ results}{No.\ of\ all\ results} \times 100\%$ = **90%**

No. of ‘True’ results: Total number of ‘True’ responses obtained from the comparison between the commercial software and the observation of the photographs of real users regarding the fitness of Chest area

No. of all results: Total number of responses obtained from the comparison between the commercial software and the observation of the photographs of real users regarding the fitness of Chest area

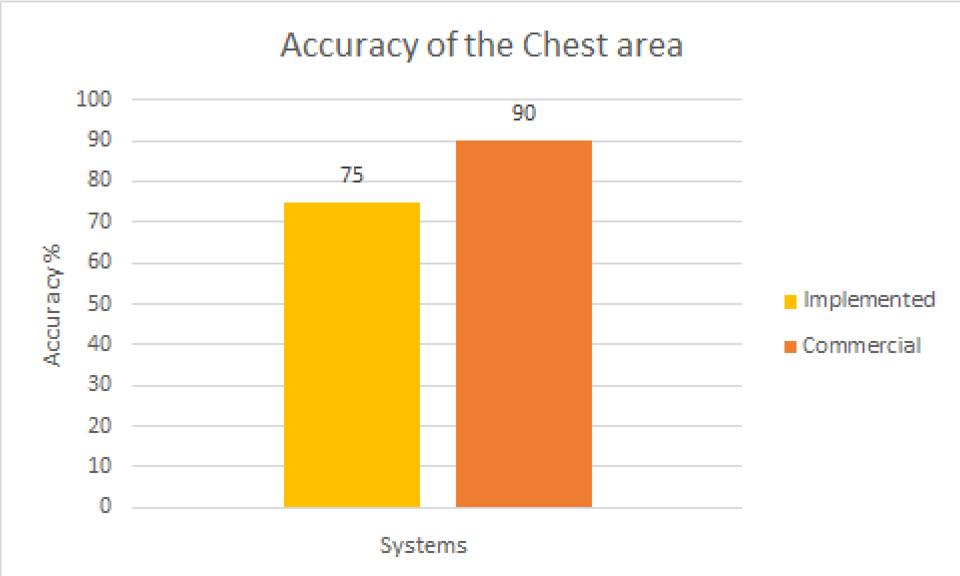


Figure 5.8. Comparison of implemented system accuracy with commercial software accuracy at chest area

5.2.3.3 Hip area

Table 5.5. Comparison of natural human observations with implemented system and commercial software at hip area

	Results through natural human observation	Results of implemented system	Results of commercial Software	Natural vs. Implemented System Comparison	Natural vs. Commercial Software Comparison
User 01	Tight fit	Tight fit	Normal/ Loose fit/ Oversize	True	False
User 02	Tight fit	Too small	Tight fit	False	True
User 03	Normal fit	Normal fit	Normal/ Loose fit/ Oversize	True	True
User 04	Tight fit	Tight fit	Tight fit	True	True
User 05	Tight fit	Tight fit	Normal/ Loose fit/ Oversize	True	True
User 06	Normal fit	Normal fit	Normal/ Loose fit/ Oversize	True	True

User 07	Loose fit	Loose fit	Normal/ Loose fit/ Oversize	True	True
User 08	Tight fit	Too small	Tight fit	False	True
User 09	Too small	Too small	Too small	True	True
User 10	Too small	Tight fit	Too small	False	True
User 11	Tight fit	Tight fit	Normal/ Loose fit/ Oversize	True	False
User 12	Tight fit	Tight fit	Tight fit	True	True
User 13	Normal fit	Normal fit	Normal/ Loose fit/ Oversize	True	True
User 14	Tight fit	Tight fit	Normal/ Loose fit/ Oversize	True	False
User 15	Tight fit	Tight fit	Tight fit	True	True
User 16	Tight fit	Tight fit	Tight fit	True	True
User 17	Oversize	Oversize	Normal/ Loose fit/ Oversize	True	True
User 18	To small	Too small	Too small	True	True
User 19	Tight fit	Tight fit	Tight fit	True	True
User 20	Tight fit	Tight fit	Tight fit	True	True

According to the comparison of implemented system results and commercial software results with real user results, the accuracy for the hip area was identified as follows.

From the comparison of actual user results with implemented system results,

Implemented System Accuracy = $\frac{No.\ of\ "True"\ results}{No.\ of\ all\ results} \times 100\%$ = **85%**

No. of ‘True’ results: Total number of ‘True’ responses obtained from the comparison between the implemented system and the observation of the photographs of real users regarding the fitness of Hip area

No. of all results: Total number of responses obtained from the comparison between the implemented system and the observation of the photographs of real users regarding the fitness of Hip area

From the comparison of actual user results with commercial software results,

Commercial Software Accuracy = $\frac{No.\ of\ "True"\ results}{No.\ of\ all\ results} \times 100\%$ = **85%**

No. of ‘True’ results: Total number of ‘True’ responses obtained from the comparison between the commercial software and the observation of the photographs of real users regarding the fitness of Hip area

No. of all results: Total number of responses obtained from the comparison between the commercial software and the observation of the photographs of real users regarding the fitness of Hip area

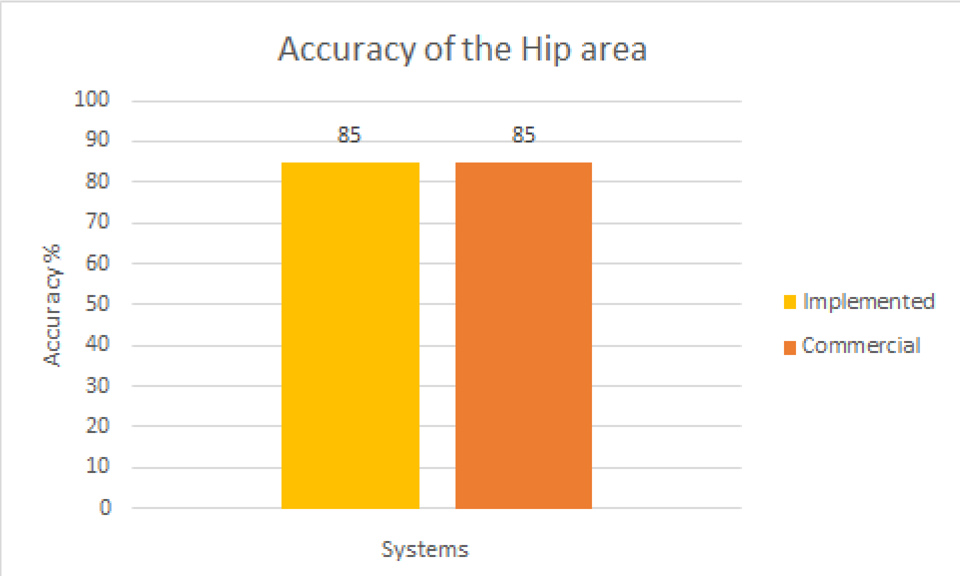


Figure 5.9. Comparison of implemented system accuracy with commercial software accuracy at hip area

5.2.3.4 Stomach area

Table 5.6. Comparison of natural human observations with implemented system and commercial software at stomach area

	Results through natural human observation	Results of implemented system	Results of commercial Software	Natural vs. Implemented System Comparison	Natural vs. Commercial Software Comparison
User 01	Loose fit	Loose fit	Normal/ Loose fit/ Oversize	True	True
User 02	Normal fit	Normal fit	Normal/ Loose fit/ Oversize	True	True
User 03	Loose fit	Loose fit	Normal/ Loose fit/ Oversize	True	True
User 04	Loose fit	Loose fit	Normal/ Loose fit/ Oversize	True	True
User 05	Tight fit	Normal fit	Tight fit	False	True
User 06	Normal fit	Normal fit	Tight fit	True	False
User 07	Oversize	Oversize	Normal/ Loose fit/ Oversize	True	True

User 08	Normal fit	Normal fit	Normal/ Loose fit/ Oversize	True	True
User 09	Tight fit	Tight fit	Tight fit	True	True
User 10	Normal fit	Normal fit	Normal/ Loose fit/ Oversize	True	True
User 11	Normal fit	Normal fit	Normal/ Loose fit/ Oversize	True	True
User 12	Normal fit	Normal fit	Normal/ Loose fit/ Oversize	True	True
User 13	Loose fit	Loose fit	Normal/ Loose fit/ Oversize	True	True
User 14	Normal fit	Loose fit	Normal/ Loose fit/ Oversize	False	True
User 15	Normal fit	Normal fit	Normal/ Loose fit/ Oversize	True	True
User 16	Loose fit	Loose fit	Normal/ Loose fit/ Oversize	True	True
User 17	Oversize	Oversize	Normal/ Loose fit/ Oversize	True	True
User 18	Normal fit	Tight fit	Normal/ Loose fit/ Oversize	False	True
User 19	Normal fit	Normal fit	Normal/ Loose fit/ Oversize	True	True
User 20	Normal fit	Normal fit	Normal/ Loose fit/ Oversize	True	True

According to the comparison of implemented system results and commercial software results with real user results, the accuracy for the stomach area was identified as follows.

From the comparison of actual user results with implemented system results,

Implemented System Accuracy = $\frac{No.\ of\ "True"\ results}{No.\ of\ all\ results} \times 100\%$ = **85%**

No. of ‘True’ results: Total number of ‘True’ responses obtained from the comparison between the implemented system and the observation of the photographs of real users regarding the fitness of Stomach area

No. of all results: Total number of responses obtained from the comparison between the implemented system and the observation of the photographs of real users regarding the fitness of Stomach area

From the comparison of actual user results with commercial software results,

Commercial Software Accuracy = $\frac{No.\ of\ "True"\ results}{No.\ of\ all\ results} \times 100\%$ = **95%**

No. of ‘True’ results: Total number of ‘True’ responses obtained from the comparison between the commercial software and the observation of the photographs of real users regarding the fitness of Stomach area

No. of all results: Total number of responses obtained from the comparison between the commercial software and the observation of the photographs of real users regarding the fitness of Stomach area

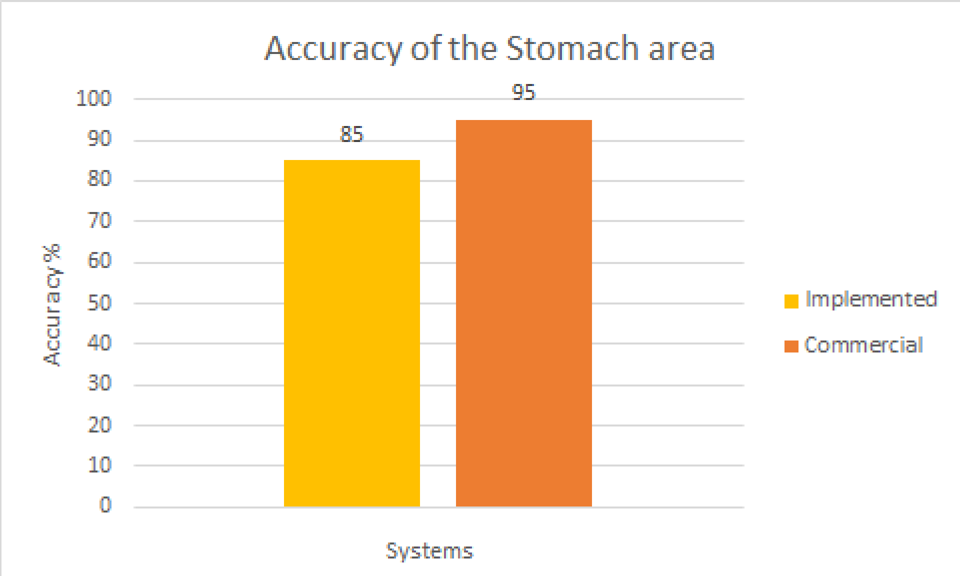


Figure 5.10. Comparison of implemented system accuracy with commercial software accuracy at stomach area

5.2.3.5 Sleeve Tightness

Table 5.7. Comparison of natural human observations with implemented system and commercial software of sleeve tightness

	Results through natural human observation	Results of implemented system	Results of commercial Software	Natural vs. Implemented System Comparison	Natural vs. Commercial Software Comparison
User 01	Tight fit	Tight fit	Tight fit	True	True
User 02	Loose fit	Normal fit	Normal/ Loose fit/ Oversize	False	True
User 03	Oversize	Loose fit	Normal/ Loose fit/ Oversize	False	True
User 04	Oversize	Oversize	Normal/ Loose fit/ Oversize	True	True
User 05	Tight fit	Loose fit	Tight fit	False	True
User 06	Normal fit	Normal fit	Normal/ Loose fit/ Oversize	True	True
User 07	Oversize	Oversize	Normal/ Loose fit/ Oversize	True	True
User 08	Normal fit	Tight fit	Tight fit	False	False
User 09	Tight fit	Tight fit	Tight fit	True	True

User 10	Tight fit	Tight fit	Tight fit	True	True
User 11	Tight fit	Tight fit	Tight fit	True	True
User 12	Normal fit	Normal fit	Normal/ Loose fit/ Oversize	True	True
User 13	Oversize	Oversize	Normal/ Loose fit/ Oversize	True	True
User 14	Tight fit	Tight fit	Tight fit	True	True
User 15	Loose fit	Normal fit	Normal/ Loose fit/ Oversize	True	True
User 16	Tight fit	Normal fit	Tight fit	False	True
User 17	Oversize	Oversize	Normal/ Loose fit/ Oversize	True	True
User 18	Loose fit	Loose fit	Normal/ Loose fit/ Oversize	True	True
User 19	Loose fit	Loose fit	Normal/ Loose fit/ Oversize	True	True
User 20	Normal fit	Normal fit	Normal/ Loose fit/ Oversize	True	True

According to the comparison of implemented system results and commercial software results with real user results, the accuracy for the sleeve tightness was identified as follows.

From the comparison of actual user results with implemented system results,

Implemented System Accuracy = $\frac{No.\ of\ "True"\ results}{No.\ of\ all\ results} \times 100\%$ = **75%**

No. of ‘True’ results: Total number of ‘True’ responses obtained from the comparison between the implemented system and the observation of the photographs of real users regarding the fitness of Shirt Sleeve

No. of all results: Total number of responses obtained from the comparison between the implemented system and the observation of the photographs of real users regarding the fitness of Shirt Sleeve

From the comparison of actual user results with commercial software results,

Commercial Software Accuracy = $\frac{No.\ of\ "True"\ results}{No.\ of\ all\ results} \times 100\%$ = **95%**

No. of ‘True’ results: Total number of ‘True’ responses obtained from the comparison between the commercial software and the observation of the photographs of real users regarding the fitness of Shirt Sleeve

No. of all results: Total number of responses obtained from the comparison between the commercial software and the observation of the photographs of real users regarding the fitness of Shirt Sleeve

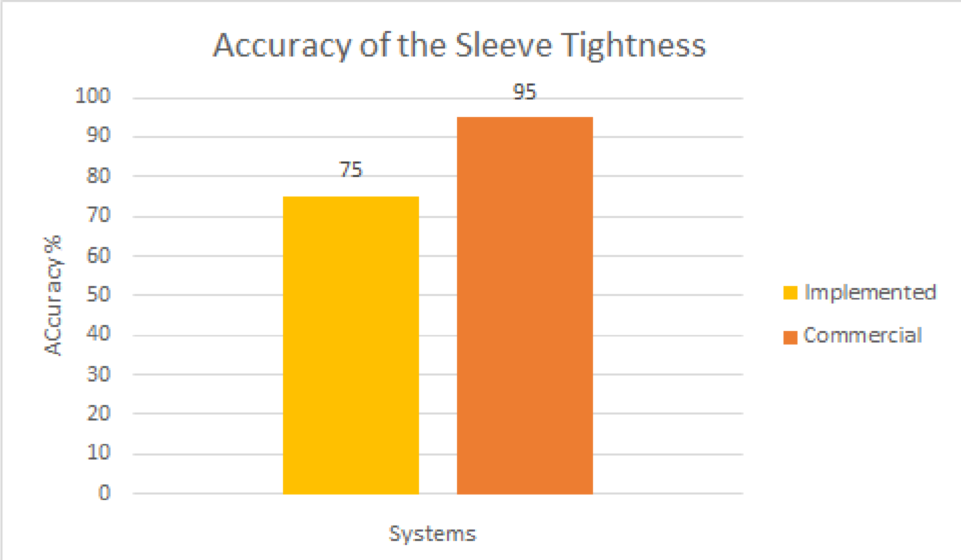


Figure 5.11. Comparison of implemented system accuracy with commercial software accuracy of sleeve tightness

Beside the aforementioned five areas the implemented system results were compared with real fitness results for two more areas namely shirt length and sleeve length. These two areas were not able to compare with the commercial software as it did not provide any indication about the length mismatch of the garment to the user apart from the stretchiness of the garment after wearing it.

5.2.3.6 Shirt Length

Table 5.8. Comparison of natural human observations with implemented system and commercial software of shirt length

	Results through natural human observation	Results of implemented system	Natural vs. Implemented System Comparison
User 01	Perfect fit	Perfect fit	True
User 02	Too long	Too long	True
User 03	Too long	Too long	True
User 04	Too short	Too long	False
User 05	Too long	Too long	True
User 06	Perfect fit	Too short	False
User 07	Perfect fit	Perfect fit	True
User 08	Perfect fit	Perfect fit	True
User 09	Too short	Perfect fit	False
User 10	Too long	Too long	True

User 11	Perfect fit	Perfect fit	True
User 12	Too long	Too long	True
User 13	Too long	Too long	True
User 14	Perfect fit	Perfect fit	True
User 15	Too long	Too long	True
User 16	Too long	Too long	True
User 17	Too long	Too long	True
User 18	Perfect fit	Perfect fit	True
User 19	Too long	Too long	True
User 20	Too long	Too long	True

According to the comparison of implemented system results and commercial software results with real user results, the accuracy for the shirt length was identified as follows.

From the comparison of actual user results with implemented system results,

Implemented System Accuracy = $\frac{No.\ of\ "True"\ results}{No.\ of\ all\ results} \times 100\%$ = **85%**

No. of 'True' results: Total number of 'True' responses obtained from the comparison between the implemented system and the observation of the photographs of real users regarding the Shirt Length

No. of all results: Total number of responses obtained from the comparison between the implemented system and the observation of the photographs of real users regarding the Shirt Length

5.2.3.7 Sleeve Length

Table 5.9. Comparison of natural human observations with implemented system and commercial software of sleeve length

	Results through natural human observation	Results of implemented system	Natural vs. Implemented System Comparison
User 01	Too long	Too long	True
User 02	Too long	Perfect fit	False
User 03	Too long	Too long	True

User 04	Too short	Too short	True
User 05	Too long	Too long	True
User 06	Too long	Too long	True
User 07	Too long	Too long	True
User 08	Perfect fit	Perfect fit	True
User 09	Too long	Too long	True
User 10	Too long	Too long	True
User 11	Perfect fit	Perfect fit	True
User 12	Too long	Too long	True
User 13	Too long	Too long	True
User 14	Perfect fit	Perfect fit	True
User 15	Perfect	Too long	False
User 16	Perfect fit	Perfect fit	True
User 17	Too long	Too long	True
User 18	Perfect fit	Perfect fit	True
User 19	Too long	Too long	True
User 20	Perfect fit	Perfect fit	True

According to the comparison of implemented system results and commercial software results with real user results, the accuracy for the sleeve length was identified as follows.

From the comparison of actual user results with implemented system results,

Implemented System Accuracy = $\frac{No.\ of\ "True"\ results}{No.\ of\ all\ results} \times 100\%$ = **90%**

No. of ‘True’ results: Total number of ‘True’ responses obtained from the comparison between the implemented system and the observation of the photographs of real users regarding the Sleeve Length

No. of all results: Total number of responses obtained from the comparison between the implemented system and the observation of the photographs of real users regarding the Sleeve Length

5.2.3.8 Overall Average Accuracy Rate

Overall accuracy rate was calculated based on the accuracy calculated for each area. The priority given to the fitness of each area when purchasing a shirt should be given a paramount consideration when identifying the overall accuracy rate hence we have conducted a survey to identify the priority preference of the male users regarding the fitness of aforesaid seven areas.

Table 5.10 contains the order of priority regarding the fitness of each area identified through the survey and the weightage values assigned subjective to the survey.

Table 5.10. Weightages of areas for the sample user set according to the priority

Area	Weightage
1. Shoulder Length	0.32K
2. Shirt Length	0.18K
3. Chest	0.15K
4. Sleeve Tightness	0.12K
5. Sleeve Length	0.10K
6. Stomach	0.08K
7. Hip	0.05K

K is a constant and it might change due to the divergence of the selected sample.

We have used the aforementioned proposed weightages to calculate the contribution of each area towards the overall accuracy of the implemented system.

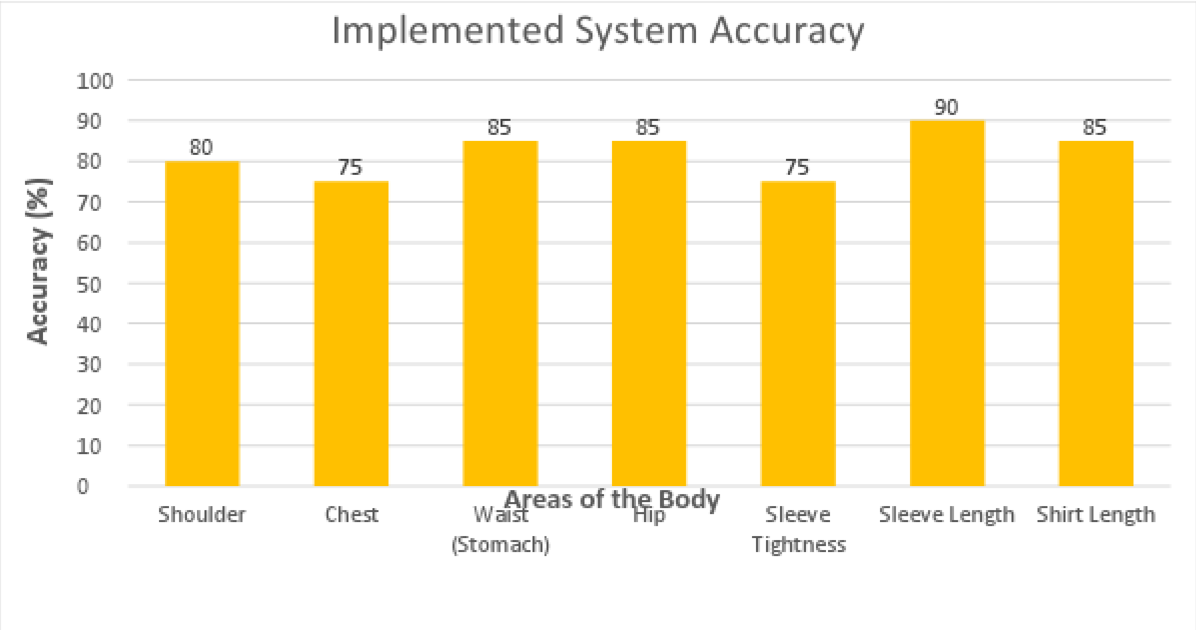


Figure 5.12. Overall accuracies of the system for the sample user set for each human body area

Contribution of an area to overall system accuracy = Accuracy rate of the area * proposed weightage of the area

We have considered K=1 instance when determining the overall accuracy of the system.

Table 5.11. Contribution of each area towards Average Overall Accuracy

Area	Accuracy rate of area	Proposed weightage	Contribution towards Overall Accuracy
1. Shoulder Length	80%	0.32	25.60%
2. Shirt Length	85%	0.18	15.30%
3. Chest	75%	0.15	11.25%
4. Sleeve Tightness	75%	0.12	9.00%
5. Sleeve Length	90%	0.10	9.00%
6. Stomach	85%	0.08	6.80%
7. Hip	85%	0.05	4.25%

Average overall accuracy of the implemented system can be obtained by summing up the contributions of each area towards the overall accuracy.

Average overall accuracy of implemented system = Summation of accuracy contributions of each area towards overall accuracy

= 81.2%

5.2.4 Discussion of the Evaluation Results

Within the evaluation process the major task was to obtain the results from natural human observation due to its subjectivity. To avoid the subjectivity, one person was used for the observations where the subjectivity of the observation turned to a constant value and errors that could occur from the subjectivity was reduced. Besides that the quantitative evaluation was unable to proceed further as it was planned to do using Marvellous Designer and CLO3D. The several drawbacks of these commercial software restricted the further proceedings of the quantitative evaluation as those software too provided results based on categorization. The proposed system was able to predict garment fit based on five fitness levels, but the strain maps generated for each garment simulation mainly represented three main colour codes ;red, yellow and green which respectively correspond to stretched garment, semi-stretched garment and un-stretched garment. Marvelous Designer and CLO3D applications did not have a mechanism to represent loose-fit or oversized areas of simulated garments. Another major reason for being unable to carry out a quantitative analysis was that it represents the garment fit in a continuous format whereas our proposed system depicts the garment fit at relative to areas of the body. As a result that evaluation also turned out to be another phase of qualitative evaluation.

5.3 Evaluation of the System Visualization Results

One of the main consideration of the research was the visualization of the system results as it was targeted at the users of the system to obtain clear understanding about the presented results. Through a survey conducted at the early stage of the research, the participants clarified about the problematic areas of the men's short sleeve shirt. Based on that results the visualization of the shirt was categorized to specific seven areas as aforementioned. Among the seven areas, it was identified that only five areas were able to represent visually whereas other two areas which represented the length of the shirt and sleeve were only able to represent in written format.

The system was implemented to evoke those five areas by splitting the shirt into those five areas and filling it with respective colours regards to the fitness in the first iteration phase (Figure 4.8). Later on, with the assistant of several group discussions, it was decided to enhance the visualization of those areas using gradient colour codes in the second iteration phase (Figure 4.9). To evaluate how effective the system visualization results another survey was conducted among set of selected users who would interest in engage with the system. They were asked about their preferences regarding the visualization of the results and determined their preference mentioning whether they were in the agreed side, disagreed side or neutral side for both iteration phases.

Based on the responses gathered, it was evidently displayed that from 25 responses, 56% disagree with the visualization of the results in the first iteration phase and 24% strongly disagree with it which indicated that out of 25 responds total 70% was unable to understand about the fitness of the shirt using first visualization. The same criteria was conducted to the visualization of system results in the second iteration phase that displayed 56% from the total respondents agreed for the visualization using colour gradients whereas 20% strongly agreed for the second visualization which indicated that total 76% from respondents were able to understand about the fitness of the shirt using second visualization. Further, when the respondents were questioned directly about their most preferred visualization method, 88% stated that their preference as the second one (Figure 4.9). With all the respondents, it was clearly visible that system users preferred the visualization in the second iteration rather than the first one.

5.3.1 Discussion of the system visualization results

The system visualization results were evaluated using 25 users who were willing to interact with the implemented system. Within this evaluation, the users of the system was evaluated and the evaluation results could be vary based on the sample size and selected set of individuals for the survey. Further, the implemented system is a prototype that contain only two iterations. If the system had been well implemented with more iterations providing more user friendly visualization methods, the results of the evaluation could have be different. Besides the evaluation results of the system visualization could be vary due to numerous reasons, for the implemented prototype system, visualization of the fitness of the shirt can be highly recognizable and more meaningful using gradient colour codes method where areas of the shirt were separated from smooth gradient lines as the fitness does not exist constant within the areas comparing to the first iteration of the visualization.

Chapter 6

Discussion, Conclusion and Future Works

This chapter contains discussion, conclusions and a summary of contributions as well as suggestions for further work correspondence to the current status of the research.

6.1 Discussion

The accuracy of proposed model have been obtained by separately considering the aforementioned seven areas, thus the accuracy of the system when determining the fitness of each individual area has been identified. The overall accuracy of the proposed solution can be deduced by considering the fitness of the aforementioned seven areas together. The overall accuracy should be able to quantify the ability of the system to measure the fitness of a particular shirt for a specific user based on the aforesaid areas. Generation of the overall accuracy is highly subjective since the decision to purchase a shirt depends on the each individual user’s requirements of fitness of different areas. A person might purchase a shirt if it has a perfect match in his shoulders while another person might consider the length of the shirt in order to make the purchase decision. Therefore we have conducted a survey in order to identify the priority order of the fitness of aforementioned areas which are considered when purchasing a shirt. The survey has been carried out among the selected sample set of users and they were asked to rank the fitness of the aforementioned seven areas which they will consider when buying a short sleeves shirt. According to the survey results, we have identified that different users have different priority lists when buying a shirt. The priority order of the areas has been identified by assigning a weightage for each area based on the survey results. Highly preferred areas for the fitness were given higher weightage when preparing the priority order. Accordingly, the overall accuracy of the proposed system has been identified for the sample set of users which we considered.

The assignment of weightages for the aforementioned seven areas have been kept open since it is highly subjective to each individual user. Considering the subjectivity of the priority given to the fitness order, it is better to authorize users to change these weightages based on their preference, when designing a software product based on the proposed methodology. More accurate priority order of the fitness could be obtained by considering a large divergent sample. The current research could be enhanced in the future by considering a more accurate rank order for fitness of the aforesaid areas which could be considered as another research area for the future researchers.

6.2 Conclusions

There are several methods and tools currently available to check the fitness of a garment with the human body. Most of these techniques demand high computational power since they deliver results utilizing available 3D technologies. Therefore time required for these applications to deliver results is relatively high and high user intervention is needed to deliver the solution. In the present social paradigm users tend to purchase items online thus the rate of the users who concurrently access these online shopping web sites is growing rapidly. It requires high-speed delivery of results in order to control the network traffic when accessing aforesaid online shopping web sites thus the applicability of aforementioned 3D applications to an online marketplace would be comparatively low. Therefore the need of a lightweight solution was identified and we have proposed a fitting model which supports the decision making process of the end user in order to select the properly fitted dress by considering human body properties and garment properties. Fitness of seven predefined areas of short sleeve shirts to male users has been presented through this research.

The following major conclusions can be derived from our research.

- The research was successful and a fitting model was proposed and implemented to support decision making process of end user to select properly fitted dress by considering human body properties and garment properties
- The scope of the proposed fitting model has been limited to the identification of the fitness of short sleeve men’s shirts
- Time required to generate the final result is negligible with respect to the extensive development and the present state of ICT since the implemented system provides 2D representation of the fitness of short sleeve men’s shirts
- The implemented system requires less user intervention since the users have to enter their specific body measurements only once to the system
- The relationship between measurements of human body and garment items has been deduced through the conducted experiment
- Generation of the 2D pattern of short sleeve men’s shirt was accomplished through the experiment and variation between finished shirt and the 2D pattern of the shirt has been identified

- Variation has been generalized and a set of equations have been generated for the comparison between human users and garment items
- A fitting model has been generated by incorporating the user preference regarding distance ease which is obtained through the experiment
- Five fitness levels have been identified as too small, tight fit, normal fit, loose fit and oversize which were used in the proposed fitting model
- A set of equations were generated based on the value ranges assigned to the fitness levels and different colours has been used to represent each fitness level
- User preference regarding the priority order of fitness corresponding to the segments in human body and preference with respect to the weightage values assigned to the segments have been incorporated when generating the final result
- Appropriateness of the visualization of fitness in final output has been evaluated by conducting a user evaluation and majority of users preferred the current visualization of the system
- The implemented system has been evaluated thoroughly using several qualitative evaluation approaches
- Over 80% of accuracy has been obtained in the identification of the fitness of hip, stomach, shirt length and sleeve length areas
- Over 70% of accuracy has been obtained in analyzing the fitness of shoulder, chest and sleeve tightness areas
- The overall accuracy of 81.2% was obtained by assigning different weightage values to the accuracy rates of these different areas
- The research process could be scalable to any other gender and garment item albeit the research was performed based on certain gender and garment item

6.2.1 Research Findings and Contributions

As one of the main contributions, our research provides a scientific method for the generation of standard 2D pattern of a finished garment item (men's short sleeve shirt) based on the experiment that has been conducted. With the assistance of the identified garment model and the 2D pattern of the human body, an appropriate model has been designed to analyze the fitness of a selected garment. For that it has been identified that user preference regarding distance ease has a significant role in fitness therefore the user preference regarding the distance ease has also been incorporated with the fitness. As a final outcome of the research, a two-dimensional web based visualization solution to indicate fitness of garment on human body using low computational power and less human intervention has been introduced to the society which will be beneficial for both retailer as well as online buyers of garment items.

Apart from the aforementioned contributions, the research aimed at enhancing the knowledge about particular research field among research community and the apparel industry by strengthening the existing literature using our implemented solution. By conducting a proper market research on male consumer behavior in purchasing shirts online, our research has been contributed to the society in the identification of online purchasing behaviour and preferences of men. Moreover a survey has been conducted to identify the priority order given to the areas regarding its concern of fitness. With that most problematic areas of the men's short sleeve shirt were determined which created the origin of fitness issues. Aforementioned seven areas in human body were discovered when purchasing short sleeve shirts by male consumers and the survey turned out to be the proper justification of the segmentation of the short sleeve shirt within the implemented system and for the future reference.

As the written contributions to the research society, a Survey paper on literature review was accepted in "International Journal of Research -Granthaalayah" as well as in the International Journal of Computer and Information Technology (IJCIT). We have published our survey paper in the volume 06 – Issue 06, November 2017 (ISSN: 2279 – 0764) in the International Journal of Computer and Information Technology (IJCIT). Moreover, a paper with consisting the design of our research has been accepted by International Journal of Information Technology and Computer Science (IJITCS).
Followings were identified as the considerable contributions of the research.

- A market survey regarding the online purchasing behaviour of men and identification of the issues they face
- A survey which interpreted the ranking order of the most problematic areas of men's shirt (short sleeve) considering the fitness and the segmentation of the areas of the shirt based on that.
- A scientific method for the generation of standard 2D pattern of a finished garment item (men's short sleeve shirt)
- A model to analyze the fitness of a selected garment comparing the garment model and the 2D pattern of the human body including the user preference regarding distance ease in it.
- A web based two-dimensional solution which visualize the fitness of the selected garment item to a particular user with low computational power and less human intervention.
- A survey regarding the evaluation of the visualization preference of the implemented system results
- Survey and research paper publications to enhance the knowledge among the research community

6.3 Future Works

The current scope of the research has been limited to fitness of short sleeve shirts to the male humans. Fitness of seven predefined areas namely shoulder, chest, stomach, hip, arm length, arm girth and shirt length has been identified and represented using different colours in order to indicate different fitness levels considering the shirt's fitness to user. We have used red colour to indicate too small areas of shirt, yellow colour to indicate tight fit areas, green colour to indicate areas with normal fit, light blue colour to indicate loose fit areas and dark blue to indicate oversized areas. The current status of the research can be enhanced in many ways considering different aspects of humans and garments.

The research can be extended to identify the fitness of the other garments of males other than the short sleeve men's shirts and also the research can be extended to females considering different garment items. The body shapes of the humans have paramount importance when considering the fitness of the garments. We have identified that there are different bodice figure issues such as large arms, slim arms, square shoulders, sloping shoulders, uneven shoulders, high bust, low bust, hollow chest, dowager hump, sway back and long back, in human figure through our study on the human body shapes. Therefore our research can be enhanced considering aforementioned different bodice figure problems. Further the visualization of the fitness can be enhanced by incorporating a heat map in order to display the different fitness levels. Improvements can be made to the developed prototype by implementing a complete web application. Moreover the current research could be improved by incorporating a more accurate weightage order which could be given to the fitness of the aforementioned seven areas in the human body. Divergent and large human sample should be considered when generating the weightage order hence generation of the weightage order could be considered as another future research area.

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Appendix A – Conducted Surveys

Survey I

First survey was conducted to identify consumer preference regarding purchasing men's shirt online. 70 participants were participated in the survey and responded their preferences with the reasons.

Survey on Consumer Preference regarding purchasing Men's shirts online

* Required

1. **Do you prefer visiting a shop to buy a shirt? ***
   Mark only one oval.
   - Yes
   - No

2. **What are your main considerations of buying a shirt? ***
   Check all that apply.
   - Collar size
   - Brand
   - Material
   - Other: ____________

3. **Do you prefer fitting-on a shirt in the shop? ***
   Mark only one oval.
   - Yes
   - No

4. **What are the most problematic areas of a short-sleeve shirt when fitting on? ***
   Check all that apply.
   - Shoulder
   - Chest
   - Stomach area
   - Length

5. **Do you prefer purchasing shirts online rather than visiting a shop? ***
   Mark only one oval.
   - Yes
   - No

6. **If 'No', what are the reasons?**
   Check all that apply.
   - Fitting Problems
   - Quality Issues
   - Other: ____________

https://docs.google.com/forms/d/1JYMnspkmEk3Zdg1HRbknnrh1plCBJ8SACSC1f0hy_A/edit 1/2

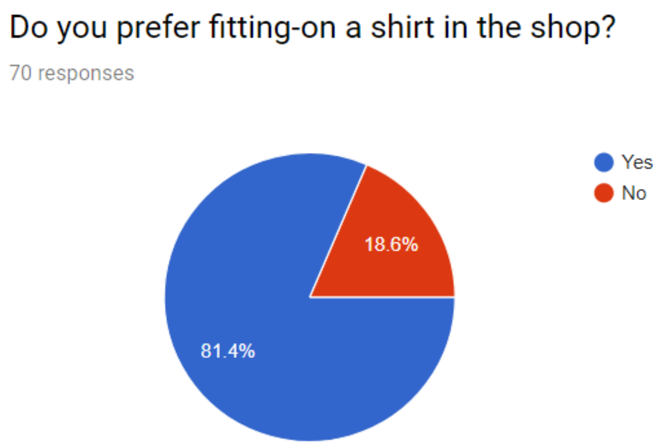
Figure A.1 Survey questions to identify consumer preference regarding online purchasing of men's shirt

Below are the responses obtained from the Survey I.

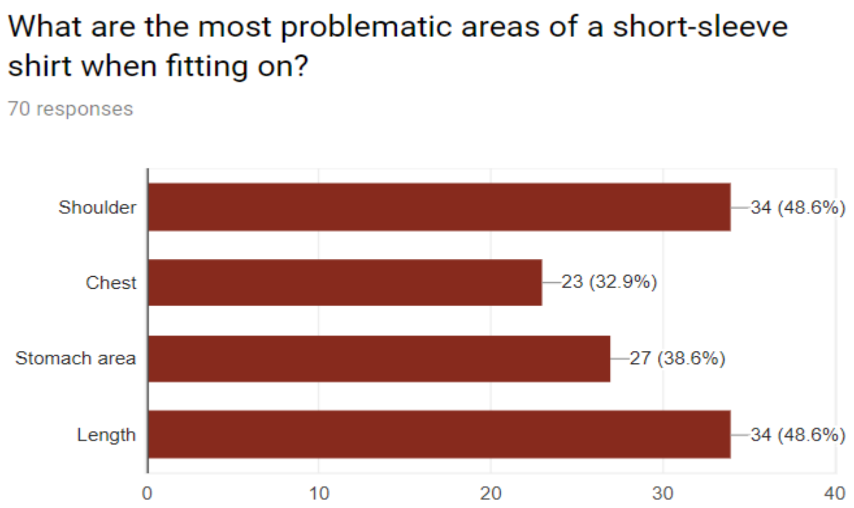
(a)


Do you prefer visiting a shop to buy a shirt?
70 responses
Yes
No
8.6%
91.4%

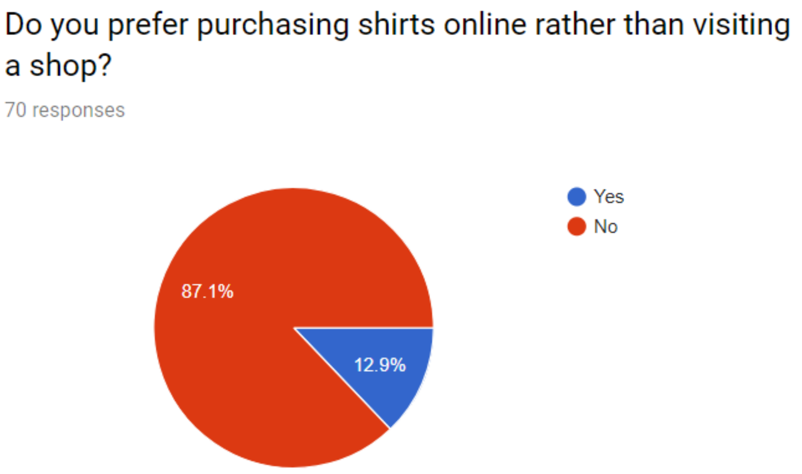
(b)


Do you prefer fitting-on a shirt in the shop?
70 responses
Yes
No
18.6%
81.4%

(c)


What are the most problematic areas of a short-sleeve shirt when fitting on?
70 responses
Shoulder
34 (48.6%)
Chest
23 (32.9%)
Stomach area
27 (38.6%)
Length
34 (48.6%)
0
10
20
30
40

(d)



.

(e)

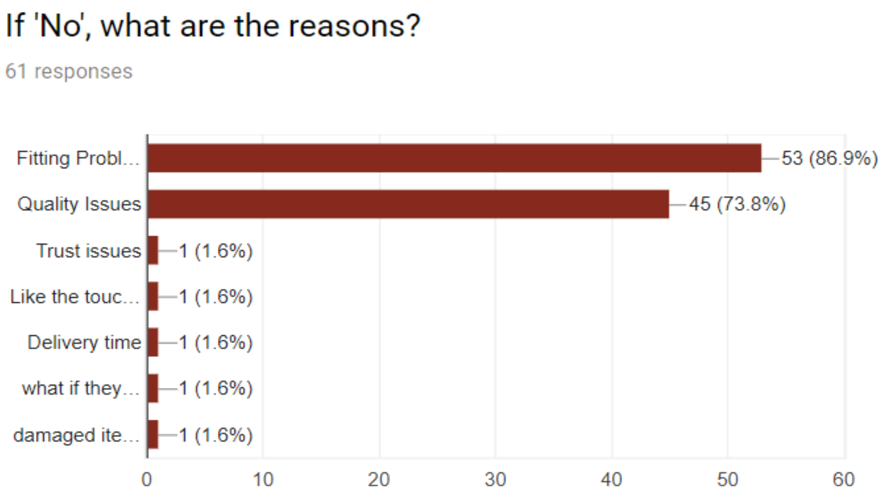


Figure A.2. Responses for the survey I

Survey II

The second survey was conducted in the evaluation phase to identify the priority given to the areas of the shirt when purchasing it. For this survey the same sample user set (20 users) that was used in the evaluation were taken part. The main areas that consider when purchasing a shirt are shoulder, chest, stomach, hip, length of the shirt, length of shirt sleeves and girth of the sleeves.

Survey Form - Rank your preference

When purchasing a shirt, generally the fitness of the areas such as shoulder, chest, stomach, hip, length of the shirt, length of shirt sleeves and girth of the sleeves are considered. This survey is to identify the priority given to these areas when purchasing a short sleeve shirt.

* Required

1. **Rank the fitness of following areas that you consider when buying a short sleeve shirt. (If you consider the fitness of the shoulder length mostly, mark it as 1.)** *

Mark only one oval per row.

	1	2	3	4	5	6	7
Shoulder Length							
Shirt Length							
Chest							
Stomach							
Hip							
Sleeve Length							
Sleeve tightness							

Powered by Google Forms

Figure A.3. Survey question to identify the priority areas of the shirt regarding fitness

Based on the responses gathered a weightage was given to the each area and that was used in calculating the accuracy of the implemented solution.

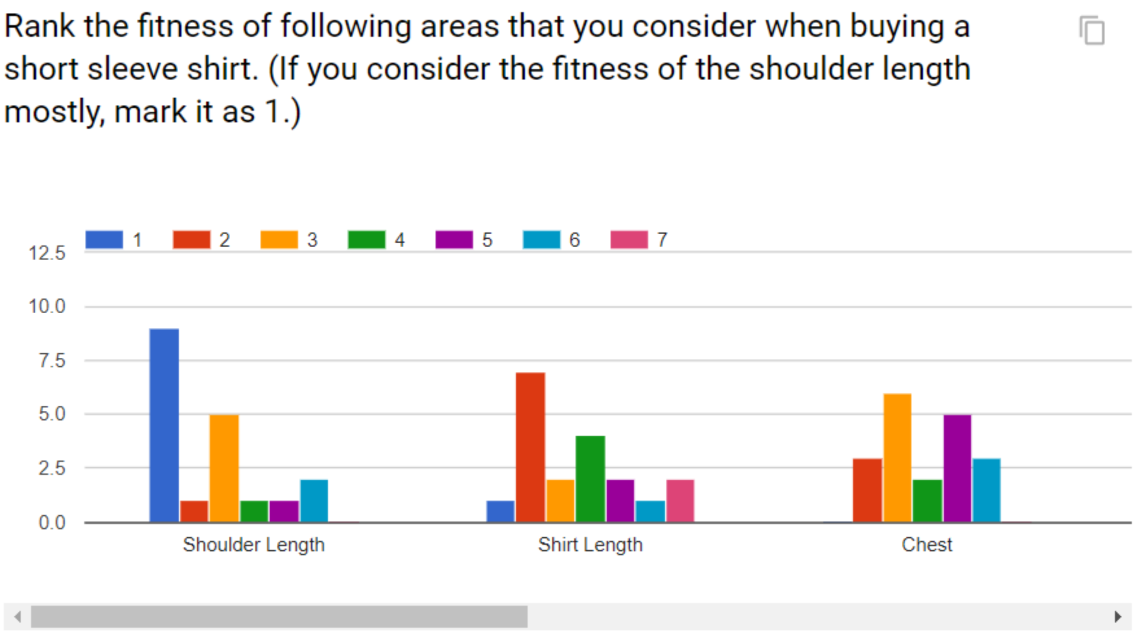


Figure A.4. Responses gathered from second survey

Survey III

The third survey was conducted again in the evaluation process with regards to the evaluation of the implemented system results visualization. The main objective of this survey was to identify the user's preferred visualization method of the system results based on its two iterations.

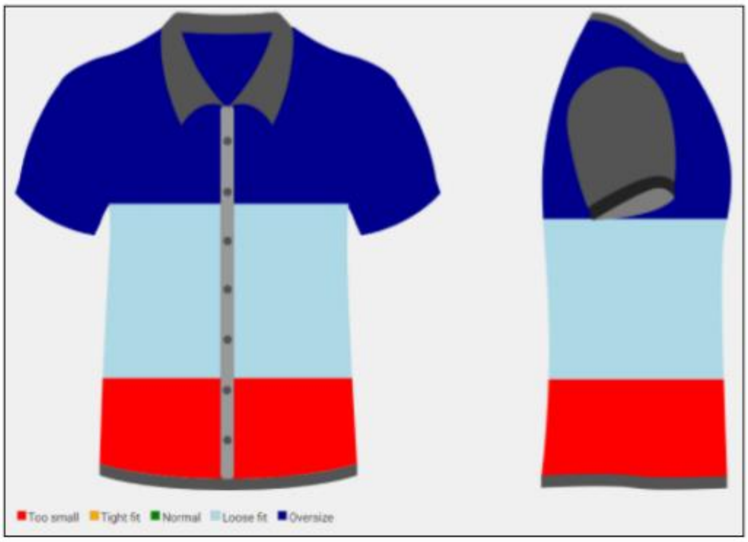
12/17/2017 Survey Form - Evaluate the Visualization

Survey Form - Evaluate the Visualization

This survey is conducted to identify the effectiveness of the visualization of the results in the implemented system and to clarify the most suitable visualization of the results

* Required

Image of the First Visualization



1. **You were able to gain a complete understanding about the fitness of the shirt using the first visualization. ***

   Mark only one oval.

   - Strongly Agree
   - Agree
   - Neither agree nor disagree
   - Disagree
   - Strongly Disagree

Image of the Second Visualization

Figure A.5.(a) Survey questions to evaluate the visualization of the system

12/17/2017 Survey Form - Evaluate the Visualization

2. **You were able to gain a complete understanding about the fitness of the shirt using the second visualization.** *

Mark only one oval.

- Strongly Agree
- Agree
- Neither agree nor disagree
- Disagree
- Strongly Disagree

3. **What is your most preferred visualization method?** *

Mark only one oval.

- First Visualization
- Second Visualization

Figure A.6. (b) Survey questions to evaluate the visualization of the system

25 users were participated in this survey and the responses were taken as follows in Figure A.6.(a), Figure A.6.(b) and Figure A.6.(c).

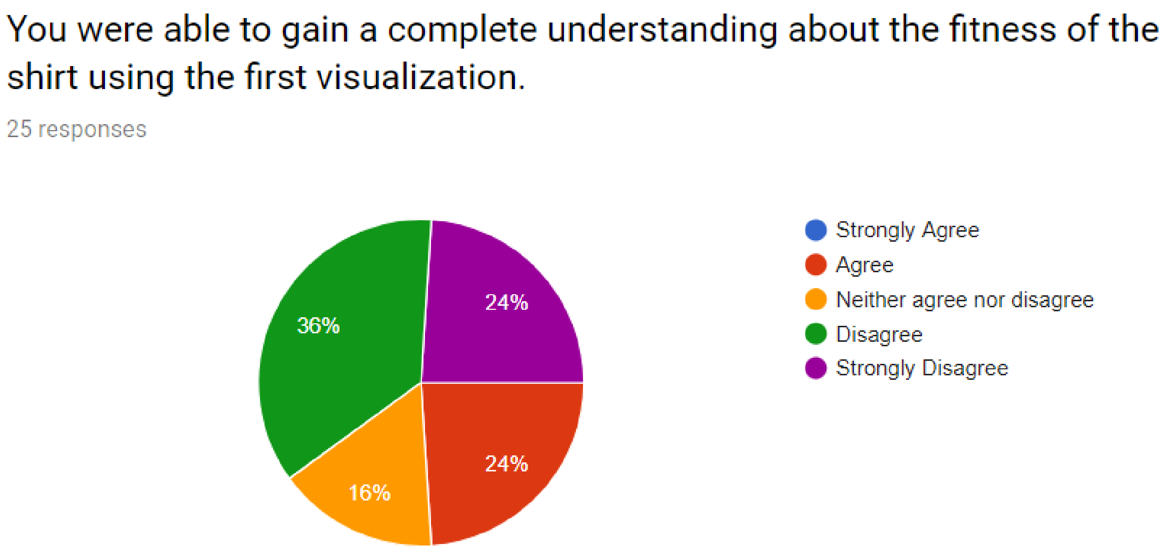


Figure A.7.(a) Response for the first question in survey III

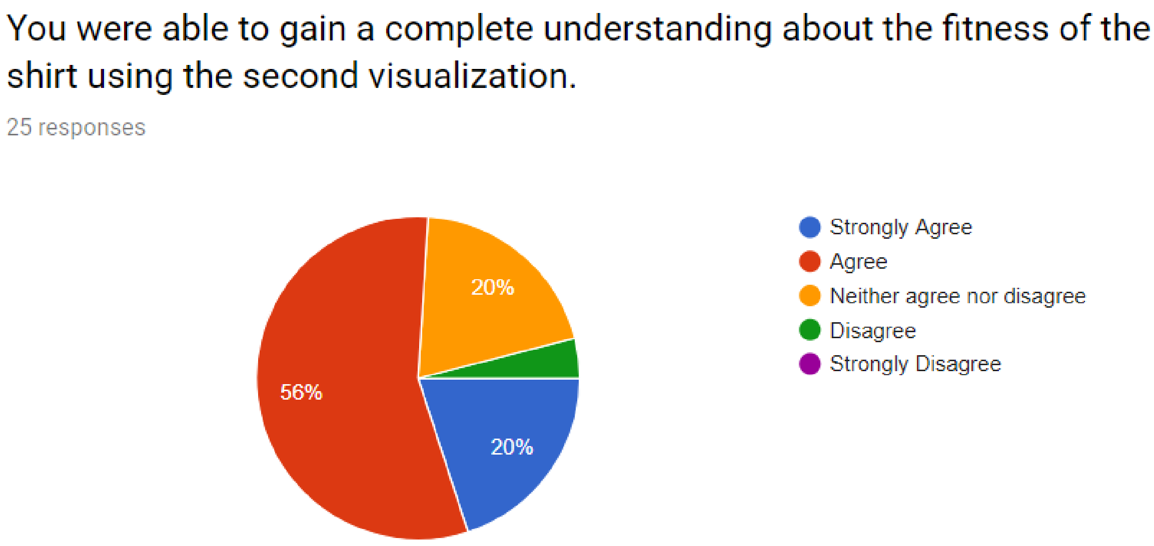


Figure A.8.(b) Response for the second question in survey III

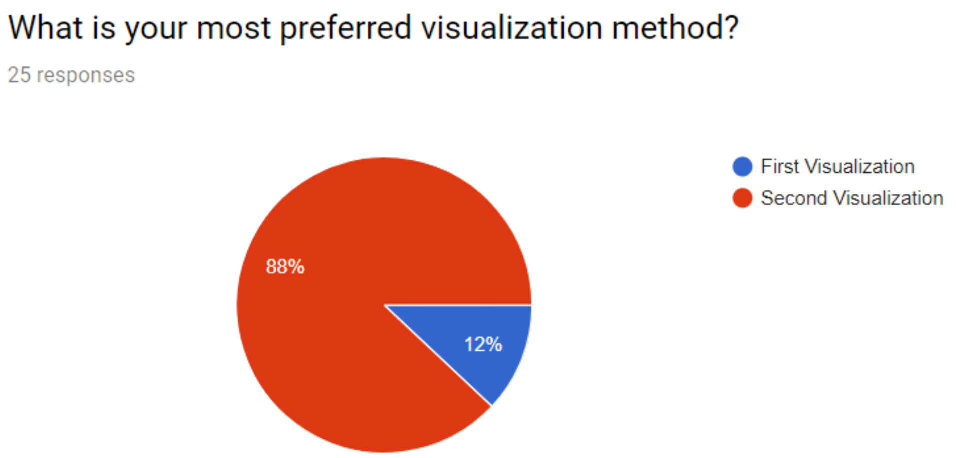


Figure A.9.(c) Response for the third question in survey III

Appendix B - Implementation

A web based system was implemented as a prototype for the proposed solution and following Figures of Figure B.1. to Figure B.9 represented the various areas in implementation process.

```
function caclDistance(x1,x2,y1,y2){
  x=Math.pow((x2-x1),2);
  y=Math.pow((y2-y1),2);
  total=x+y;
  distance= Math.sqrt(total);
  return distance;
}
```

Figure B.1. Function for finding the distance among two points

```
function calcShoulderFitness(shirtCollarSize,userPreference,shirtLengthFromShoulderToHip, shirtFullShoulderWidth, shirtCollarWidth,
  shirtLengthFromCollarToShoulder,humanLengthFromWaistToHip, humanLengthFromSideNeckToWaist,humanLengthFromSideShoulderToWaist,
  humanNeckBaseWidth, humanNeckGirth){
  errorShoulderWidth= -2.110 + 0.1800*shirtCollarSize;
  errorCollarWidth= -7.495 + 0.6100*shirtCollarSize;
  errorLengthFromCollarToShoulder=0;
  errorLengthFromShoulderToHip= -5.030 + 0.3400*shirtCollarSize;

  x21=humanNeckGirth/6 +0.5;
  x22=humanNeckBaseWidth/2;
  y21=humanLengthFromWaistToHip+humanLengthFromSideNeckToWaist;
  y22=humanLengthFromWaistToHip+humanLengthFromSideShoulderToWaist;
  fg=caclDistance(x21,x22,y21,y22);

  angleHumanCosValue= ((humanNeckBaseWidth/2)-((humanNeckGirth/6)+0.5))/fg;
  angleHumanCosInverseValue=Math.acos(angleHumanCosValue);
  z= ((humanNeckBaseWidth/2)-((humanNeckGirth/6)+0.5)) * Math.tan(angleHumanCosInverseValue);

  angleShirtCosValue=(((shirtFullShoulderWidth+errorShoulderWidth)/2) - ((shirtCollarWidth+errorCollarWidth)/2))/
  (shirtLengthFromCollarToShoulder+errorLengthFromCollarToShoulder);
  angleShirtCosInverseValue=Math.acos(angleShirtCosValue);
  h2=((shirtFullShoulderWidth+errorShoulderWidth)/2)*Math.tan(angleShirtCosInverseValue);

  y11= shirtLengthFromShoulderToHip+errorLengthFromShoulderToHip+h2;
  x12=(shirtFullShoulderWidth+errorShoulderWidth)/2;
  y12=shirtLengthFromShoulderToHip+errorLengthFromShoulderToHip;
  shirtShoulderLength=caclDistance(0,x12,y11,y12);

  y31=humanLengthFromWaistToHip+humanLengthFromSideNeckToWaist+z;
  x32=humanNeckBaseWidth/2;
  y32=humanLengthFromWaistToHip+humanLengthFromSideNeckToWaist;
  humanShoulderLength=caclDistance(0,x32,y31,y32);
  diffShoulderLength=(shirtShoulderLength-humanShoulderLength).toFixed(1);
  return diffShoulderLength;
}
```

Figure B.2. Function for the shoulder fitness

```
function calcChestFitness(shirtCollarSize,userPreference,shirtLengthFromShoulderToHip,shirtChest,shirtSeamLength,shirtBackLengthFromMiddle,
  shirtFrontLengthFromMiddle, humanChest,humanWaist, humanWaistToHip,humanUnderArmToWaist, humanLengthFromSideNeckToWaist){
  //errorSeamLength= -12.20 + 0.8000*shirtCollarSize;
  //errorBackLengthFromMiddle= -11.32 + 0.7600*shirtCollarSize;
  errorChest= -2.835 + 0.2300*shirtCollarSize;

  shirtChestPattern= (shirtChest+errorChest)/2;//26.9225
  humanChestPattern=(humanChest/2 +1)/2 - 0;//28.95
  diffChest=(shirtChestPattern-humanChestPattern).toFixed(1);

  if(diffChest< 0.25){
    //'Shirt is small'
    return 1;
  }else if(diffChest >= 0.25 && diffChest< 0.5){
    //'Tight fit'
    return 2;
  }else if(diffChest >=0.5  && diffChest< 2.5){
    //'Normal fit'
    return 3;
  }else if(diffChest >=2.5 && diffChest<= 4.8){
    //'Comfort Fit'
    return 4;
  }else{
    //oversize
    return 5;
  }
}
```

Figure B.3. Function for the fitness of the chest

```
function calcShirtLengthFitness(shirtCollarSize, userPreference,shirtLengthFromShoulderToHip,humanSideShoulderToWaist,humanWaistToHip){
  errorLengthFromShoulderToHip= -5.030 + 0.3400*shirtCollarSize;
  shirtLength=shirtLengthFromShoulderToHip+errorLengthFromShoulderToHip;
  humanShirtLength=humanSideShoulderToWaist+humanWaistToHip;
  diffLength= Math.round(shirtLength-humanShirtLength);
  return diffLength;
  //you should diplay output as shirt is x cm shorter than expected level. here x=diffLength
}
```

Figure B.4. Functions for the fitness of the hip and the shirt length

```javascript
function calcArmGirthFitness(shirtCollarSize,userPreference,shirtUpperArmGirth,humanArmGirth){
  errorUpperArmGirth= -7.54 + 0.5200*shirtCollarSize;//0.78
  shirtArmGirth= shirtUpperArmGirth+errorUpperArmGirth;//46.18
  diffArmGirth= shirtArmGirth-humanArmGirth;

  if(diffArmGirth<5){
    //'Shirt is small'
    return 1;
  }else if(diffArmGirth >= 5 && diffArmGirth< 9){
    //'Tight fit'
    return 2;
  }else if(diffArmGirth >= 9 && diffArmGirth< 13){
    //'Normal fit'
    return 3;
  }else if(diffArmGirth >=13 && diffArmGirth< 16){
    //'Comfort Fit'
    return 4;
  }else{
    //oversize
    return 5;
  }
}

function calcArmLengthFitness(shirtCollarSize,userPreference,shirtUpperArmLength,humanArmLength){
  errorUpperArmLength= -11.50 + 0.8000*shirtCollarSize;
  shirtArmLength=shirtUpperArmLength+errorUpperArmLength;
  diffArmLength= Math.round(shirtArmLength-humanArmLength);
  return diffArmLength;
  //you should diplay output as shirt arm is y cm shorter than expected level. here y=diffArmLength

}
```

Figure B.5. Functions for the arm girth and arm length

```javascript
function calcStomachFitness(shirtCollarSize,userPreference,shirtWaist,humanWaist){
  errorShirtWaist= 5.85 -0.3500* shirtCollarSize ;
  shirtWaistPattern= (shirtWaist+errorShirtWaist)/2 - 0;
  humanWaistPattern=(((humanWaist/2)+1)/2)-0;

  diffStomach=shirtWaistPattern-humanWaistPattern;

  if(diffStomach<0.8){
    //'Shirt is small'
    return 1;
  }else if(diffStomach >= 0.8 && diffStomach< 2){
    //'Tight fit'
    return 2;
  }else if(diffStomach >= 2 && diffStomach< 5){
    //'Normal fit'
    return 3;
  }else if(diffStomach >=5 && diffStomach< 7){
    //'Comfort Fit'
    return 4;
  }else{
    //oversize
    return 5;
  }

}
```

Figure B.6. Function for the fitness of stomach area

```
  var o = {};
  o.getVendorMeasurements = function(){return o.vendorMeasurements;};
  o.setVendorMeasurements = function(m){
    o.vendorMeasurements = m
  };
  o.getBuyerMeasurements = function(){return o.buyerMeasurements;};
  o.setBuyerMeasurements = function(m){
    o.buyerMeasurements = m
  };
  o.getResults = function(cb) {
    var results = {};
    var userPreference='Normal Fit'

    results.stomach = calcStomachFitness(o.vendorMeasurements.collar, userPreference, o.vendorMeasurements.swaist, o.buyerMeasurements.hwaist);
    results.armLength = calcArmLengthFitness(o.vendorMeasurements.collar, userPreference, o.vendorMeasurements.ual, o.buyerMeasurements.ual);
    results.armGirth = calcArmGirthFitness(o.vendorMeasurements.collar, userPreference, o.vendorMeasurements.uag, o.buyerMeasurements.uag);
    results.hip = calcHipFitness(o.vendorMeasurements.collar, userPreference, o.vendorMeasurements.wlh, o.buyerMeasurements.hip);
    results.shoulder = calcShoulderFitness(o.vendorMeasurements.collar, userPreference, o.vendorMeasurements.flfs,o.vendorMeasurements.sw,
      o.vendorMeasurements.cw,o.vendorMeasurements.lfcs, o.buyerMeasurements.w2h, o.buyerMeasurements.sntw, o.buyerMeasurements.stw,
      o.buyerMeasurements.nb, o.buyerMeasurements.ng);
    results.shirtLength = calcShirtLengthFitness(o.vendorMeasurements.collar, userPreference, o.vendorMeasurements.flfs, o.buyerMeasurements.stw,
      o.buyerMeasurements.w2h );

    results.chest = calcChestFitness(o.vendorMeasurements.collar, userPreference, o.vendorMeasurements.flfs, o.vendorMeasurements.chest,
                    o.vendorMeasurements.sl, o.vendorMeasurements.blfm, o.vendorMeasurements.flfm,
                    o.buyerMeasurements.chest, o.buyerMeasurements.hwaist,
                    o.buyerMeasurements.w2h, o.buyerMeasurements.ua2w,);

    return cb(results);
  };
  return o;

});
```

Figure B.7. Steps of executing the fitness functions

```
APIService.getBuyerMeasurements().then(function(res){
  $scope.measurements = res.data[res.data.length-1];
  Measurements.setBuyerMeasurements($scope.measurements);
  console.log(res);
});
$scope.description = {};
APIService.getShirts().then(function(res){
  var shirt = res.data.data[res.data.data.length-1];
  Measurements.setVendorMeasurements(shirt);
  Measurements.getResults(function(results){
    console.log(results);
    $scope.results = results;
    for (var part in $scope.results) {
      console.log(part);
      if (part === "shirtLength") {
        var shirtLength = $scope.results[part];
        console.log("shirtLength", shirtLength);
        if (shirtLength < 0) {
          var description = Math.abs(shirtLength) + "cm shorter than expected length";
          $scope.description["shirtL"] = description;
        } else if (shirtLength > 0) {
          $scope.description["shirtL"] = shirtLength + "cm longer than expected length";
        } else {
          //alert(shirtLength);
          /*if(!isNaN(shirtLength)){
            $scope.description["shirtL"] = shirtLength + "cm. A perfect match";
          }else{*/
            $scope.description["shirtL"] = "A perfect match";
          //}

        }
```

Figure B.8. (a) Generating the final output

```
      }
    } else if (part === "armLength") {
      var arm = $scope.results[part];
      var shoulderDiff = $scope.results["shoulder"];
      //alert(shoulderDiff);
      var armLength= (parseFloat(arm) + parseFloat(shoulderDiff)).toFixed(2);
      console.log(armLength);
      if (armLength < 0) {
        var description = Math.abs(armLength) + "cm shorter than expected length";
        $scope.description["armL"] = description;
      } else if (armLength > 0) {
        $scope.description["armL"] = armLength + "cm longer than expected length";
      } else {
        /*if(!isNaN(armLength)){
          $scope.description["armL"] = armLength + "cm. A perfect match";
        }else{*/
          $scope.description["armL"] = "A perfect match";
        //}

      }
    } else if (part === "shoulder") {
      var shoulder = $scope.results[part];
      console.log(shoulder);
      if (shoulder < 0) {
        var description = Math.abs(shoulder) + "cm shorter than expected length";
        $scope.description["shoulder"] = description;
      } else if (shoulder > 0) {
        $scope.description["shoulder"] = shoulder + "cm longer than expected length";
      } else {
        /*if(!isNaN(shirtLength)){
          $scope.description["shoulder"] = shirtLength + "cm. A perfect match";
        }else{*/
          $scope.description["shoulder"] = "A perfect match";
        //}
      }
    } else {
      $scope.description[part] = ClothMapping[$scope.results[part]];
    }
  }
  loadSVG();
 });
})
```

Figure B.9. (b) Generating the final output

```
$scope.cellColor = function(component) {
  console.log(component);
  if (component === 'Too Small') return 'small';
  else if (component === 'Oversized') return 'big';
};

function loadSVG(){

  var s = Snap("#svg");
  Snap.load("shirt.svg", onSVGLoaded ) ;

  function onSVGLoaded( data ){
    console.log(data);
    s.append( data );
    var svgs = document.getElementsByTagName("svg");
    var svg = svgs[0],
    box = svg.getBBox(), // <- get the visual boundary required to view all children
    viewBox = [box.x, box.y, box.width, box.height].join(" ");
    svg.setAttribute("viewBox", viewBox);

    function fillColor(component, category) {
      console.log("fill color", component, category);
      if (category == 1) {
        component.attr('class', 'small');
      } else if (category == 2) {
        component.attr('class', 'tight');
      } else if (category == 3) {
        component.attr('class', 'normal');
      } else if (category == 4) {
        component.attr('class', 'loose');
      } else if (category == 5) {
        component.attr('class', 'oversize');
      }
    }

    for (var part in $scope.results) {
      console.log(part, $scope.results[part]);
      if (part == "stomach") {
        var stomach = Snap.select("#stomach");
        var stomachSide = Snap.select("#stomach_1_");
        fillColor(stomach, $scope.results[part]);
        fillColor(stomachSide, $scope.results[part]);
```

Figure B.10. (a) Steps of applying colours to the shirt

```
      } else if (part == "armGirth") {
        console.log('girth');
        var armGirthRight = Snap.select("#hand-right_1_");
        var armGirthLeft = Snap.select("#hand-left_1_");
        var armGirthLeftSide = Snap.select("#hand");

        fillColor(armGirthLeft, $scope.results[part]);
        fillColor(armGirthRight, $scope.results[part]);
        fillColor(armGirthLeftSide, $scope.results[part]);

      } else if (part == "hip") {
        var hip = Snap.select("#hip_1_");
        var hipSide = Snap.select("#hip_3_");
        fillColor(hip, $scope.results[part]);
        fillColor(hipSide, $scope.results[part]);
      } else if (part == "chest") {
        var shoulder = Snap.select("#chest2");
        var shoulderSide = Snap.select("#chest_1_");
        fillColor(shoulder, $scope.results[part]);
        fillColor(shoulderSide, $scope.results[part]);
      }
    }
  }
}
}]);
```

Figure B.11. (b) Steps of applying colours to the shirt

Appendix C - Evaluation Process

For the both evaluation processes sample set of 20 users joined and their results were compared with the images that were taken when they wore the same particular shirt. The comparison of five users as follows.

- **User 06**

Area	Fitness Level
Stomach	Normal
Sleeve Length	4.40cm longer than expected length
Sleeve Tightness	Normal
Hip	Normal
Shoulder	2.4cm longer than expected length
Shirt Length	6cm shorter than expected length
Chest	Normal

Figure C.1.(a) Implemented system results for user 06

Figure C.2. (b) Real image (left) and the results taken from commercial s/w (right) of user 06

➢ **User 07**

Area	Fitness Level
Stomach	Oversized
Sleeve Length	5.40cm longer than expected length
Sleeve Tightness	Oversized
Hip	Loose Fit
Shoulder	3.4cm longer than expected length
Shirt Length	2cm longer than expected length
Chest	Loose Fit

Figure C.3.(a) Implemented system results for user 07

Figure C.4.(b) Real image (left) and the results taken from commercial s/w (right) of user 06

➢ **User 09**

Area	Fitness Level
Stomach	Tight
Sleeve Length	12.30cm longer than expected length
Sleeve Tightness	Tight
Hip	Too Small
Shoulder	5.3cm longer than expected length
Shirt Length	2cm longer than expected length
Chest	Too Small

Figure C.5.(a) Implemented system results for user 09

Figure C.6.(b) Real image (left) and the results taken from commercial s/w (right) of user 09

➢ **User 11**

Area	Fitness Level
Stomach	Normal
Sleeve Length	A perfect match
Sleeve Tightness	Tight
Hip	Tight
Shoulder	A perfect match
Shirt Length	1cm longer than expected length
Chest	Loose Fit

Figure C.7.(a) Implemented system results for user 11

Figure C.8.(b) Real image (left) and the results taken from commercial s/w (right) of user 11

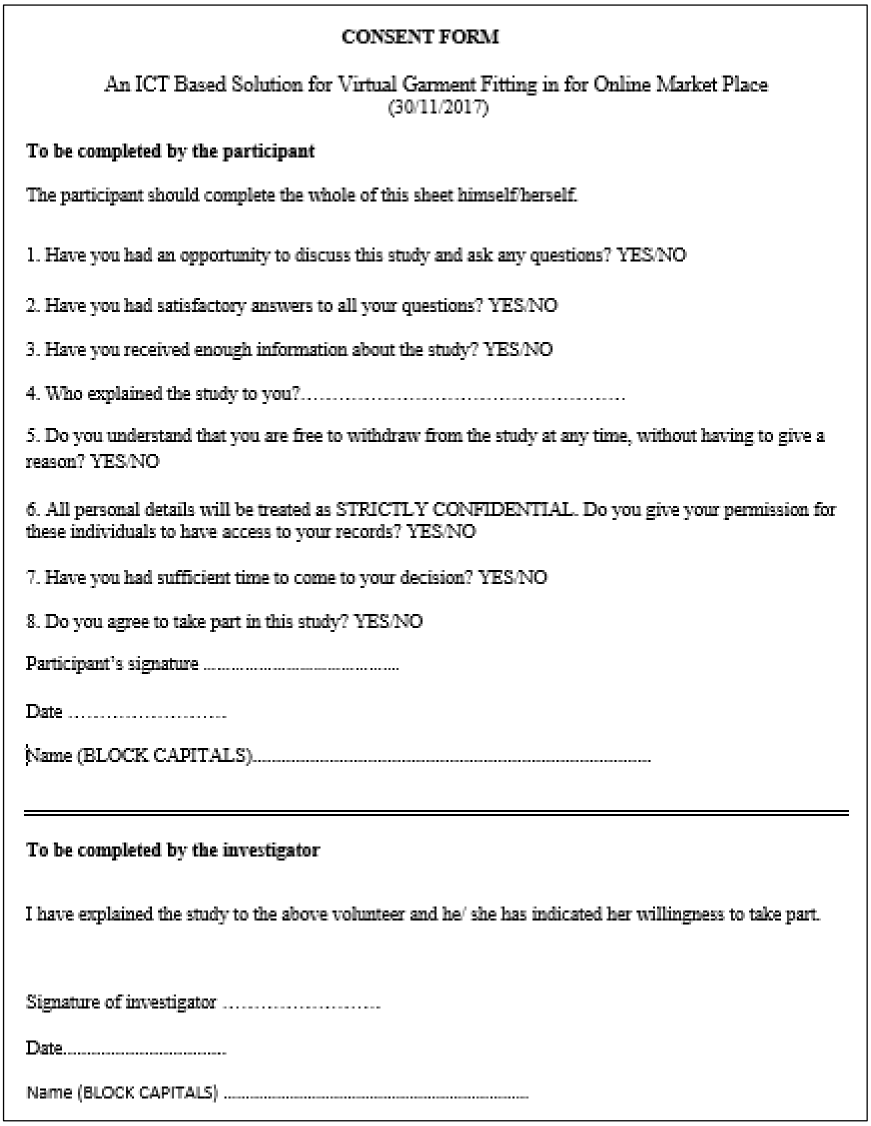
➢ **User 14**

Area	Fitness Level
Stomach	Loose Fit
Sleeve Length	0.8cm shorter than expected length
Sleeve Tightness	Tight
Hip	Tight
Shoulder	0.8cm shorter than expected length
Shirt Length	1cm longer than expected length
Chest	Loose Fit

Figure C0.9.(a) Implemented system results for user 14

Figure C.10.(b) Real image (left) and the results taken from commercial s/w (right) of user 14

Appendix D – Consent Form



CONSENT FORM

An ICT Based Solution for Virtual Garment Fitting in for Online Market Place
(30/11/2017)

To be completed by the participant

The participant should complete the whole of this sheet himself/herself.

1. Have you had an opportunity to discuss this study and ask any questions? YES/NO

2. Have you had satisfactory answers to all your questions? YES/NO

3. Have you received enough information about the study? YES/NO

4. Who explained the study to you?……………………………………………

5. Do you understand that you are free to withdraw from the study at any time, without having to give a reason? YES/NO

6. All personal details will be treated as STRICTLY CONFIDENTIAL. Do you give your permission for these individuals to have access to your records? YES/NO

7. Have you had sufficient time to come to your decision? YES/NO

8. Do you agree to take part in this study? YES/NO

Participant's signature ……………………………………

Date ……………………

Name (BLOCK CAPITALS)………………………………………………………………………

To be completed by the investigator

I have explained the study to the above volunteer and he/ she has indicated her willingness to take part.

Signature of investigator ……………………

Date………………………………

Name (BLOCK CAPITALS) ………………………………………………………

Figure D.1. Consent form given to the participants