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Kinematic modeling of a motorcycle rider for design of functional clothing

Kanika Jolly
Department of Design, Indian Institute of Technology Delhi, New Delhi, India
Sybille Krzywinski
Department of Ready-made Clothing Technology,
Institute of Textile Machinery and High Performance Material Technology,
Dresden, Germany
PVM Rao
Department of Design, Indian Institute of Technology Delhi, New Delhi, India, and
Deepti Gupta
Department of Textile Technology, Indian Institute of Technology Delhi,
New Delhi, India

Abstract

Purpose – Whilst motorcycling is an activity of pleasure in most parts of the world, in India, it is a regular mode of commuting. The number of registered motorized two wheelers increased at the rate of 14.7 percent during the year 2016-2017 to reach the figure of 20.19m in 2018. But, with this increase, the number of motorcycle road accidents is also increasing. Uncomfortable riding clothing is one of the major factors for motorcycle rider's muscular fatigue, which might at times lead to serious accidents. No kinematic human models have been, so far, used for the design of protective, functional and aesthetic looking products, and the result is, hence, a compromised fit that is not protective or comfortable. The purpose of this paper is to develop virtual 3D human body models for specific postures of a motorcycle rider.

Design/methodology/approach – Kinematic analysis of a motorcycle rider was conducted to identify typical body postures obtained by the motorcycle rider while mounting and riding a motorcycle. The identified body postures were mapped on a virtual parametric human model to obtain digital model of a motorcycle rider. 3D garment patterns for jacket and trouser were developed on all the four body postures. 3D patterns were flattened out to get 2D flat patterns that were compared and analyzed, and appropriate pattern shapes from each of the four postures were selected. Virtual fit analysis was conducted for the finally garment.

Findings – It is well established that a static 2D anthropometry fails to accurately capture the dimensions of complex 3D human form, yielding poor garment fit. Therefore, in this study, virtual, 3D human body models were developed in selected dynamic poses. Garment patterns developed in 3D have the typical movement inbuilt in them; hence, they offer more comfort and ease of motion to the wearer.

Originality/value – The identification of typical body postures of motorcycle rider has not been done before. The CAD models developed in the study can be used for the generation of ergonomic garment patterns for the motorcycle riders.

Keywords Computer-aided design, Pattern making, 3D human body modelling, Functional clothing, Kinematic analysis

Paper type Research paper

1. Introduction

Motorcycling is an activity of pleasure in most parts of the world; in India, it is a regular mode of commuting. Motorcycles have become a style statement for the majority of youth in the country, besides serving as a convenient and affordable means to commute in the urban areas. Due to the road condition, lower prices and greater fuel economy, it has also become a preferred means of transport in the rural countryside. Motorcycles are used at work environment for various activities such as fast food delivery, deliver posts and police patrols. Due to such fondness of the

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motorcycles, a positive increase in the number of registered motorized two wheelers (motorcycle, scooter and moped) has been noted, which increased at the rate of 14.7 percent during the year 2016–2017 to reach the figure of 20.19min 2018, which are currently in circulation, and their number is still on a rise (MoRTH, 2018). But, with this increase in the number of riders, unfortunately, the number of motorcycle road accidents is also on the rise. Globally, 49 percent of deaths from traffic crashes occur among vulnerable road users, including pedestrians, bicyclists and motorcyclists. Approximately, a quarter of those killed are motorcyclists. However, this is a disproportionately distributed phenomenon across the world with South East Asian Regions and Western Pacific Region each accounting for 34 percent of the world's motorcycle rider deaths (WHO, 2015). Motorcyclists represent an increasing proportion of road crash casualties having a higher risk of injury than other motorized road users (Chang and Yeh, 2007; Ma'arof *et al.*, 2015; Mohan *et al.*, 2017). Motorcycle, as a single-track vehicle with no integral protective structure is intrinsically less protective than a car. For a motorcyclist, the road fatality risk with respect to the distance traveled is 35 times higher than a passenger traveling by car (NHTSA, 2012). In light of these alarming statistics, there is an urgent need to identify strategies for reducing the risk of injury to motorcycle riders.

A number of researchers have concluded that effective injury prevention is most likely to come from protection systems worn by the rider rather than attached to the motorcycle (Ouellet *et al.*, 1987; Liz de Rome *et al*, 2012). Also, significant evidence is available in literature to indicate that wearing protective clothing can play a critical role in protecting the motorcycle rider from severe injuries in case of an accident (EEVC, 1993; Otte *et al.*, 2002; ACEM 2004; Liz de Rome, Ivers, Haworth, Heritier, Du and Fitzharris, 2011; Liz de Rome, Ivers, Fitzharris, Du, Richardson and Haworth, 2011; Meredith *et al.*, 2015). Motorcycle riders wear multiple layers of clothing while riding a motorcycle primarily to protect themselves from various injuries in case of an accident and second to protect themselves from the various elements of the environment. Motorcycle clothing is exposed to high levels of abrasion and impact in case the motorcycle rider falls from the motorcycle and slides along the tarmac (Varnsverry, 2005; Zwolińska, 2013; Meredith *et al.*, 2015).

Multiple clothing layers worn by the rider may restrict the riders body movements and add on to the fatigue levels of the motorcycle rider that might even lead to motorcycle accidents. Although the motorcycle accident is a multi-factorial phenomenon, uncomfortable riding posture is one of the major factors for rider's muscular fatigue (Arunachalam *et al.*, 2019). Therefore, there is a need of designing ergonomic motorcycle protective clothing that fits and protects the motorcyclists from injuries and unfavorable climatic conditions and reduce the motorcycle riding fatigue caused by uncomfortable protective clothing.

The series of European standards (EN) 13595 assess the requirements, such as strength, abrasion resistance or cut resistance, for motorcycle protective clothing (jackets, trousers and one piece or divided suits). The technical basis for EN 13595 is largely based on the work conducted by R. I. Woods (Woods, 1996a). Although this standard was released in the year 2002, they were revaluated, more than a decade later, by a group of researchers in Australia, which proved that with minor adjustments, the general concept and principles of the zones used in the EU standards for motorcycle protective clothing were still valid (Meredith *et al.*, 2014).

As per the standard, EN 13595-2 (2002), the body of a motorcycle rider is divided into four zones (Zone 1, Zone 2, Zone 3 and Zone 4) (Figure 1). Areas of the body lying under Zone 1 (regions include knees, elbows, shoulders and hips) are considered as the high impact areas and, hence, require impact protectors, whereas the areas under Zone 2 are the high abrasion risk areas, Zone 3 comes under moderate risk of abrasion damage and Zone 4 areas are the areas that has the lowest frequency of impact and abrasion damage; hence, this zone can be used to provide ventilation.

According to this standard, the minimum abrasion resistance requirements (in seconds) of the material for use over high impact areas of the body (Zones 1 and Zone 2) are 4.0 s

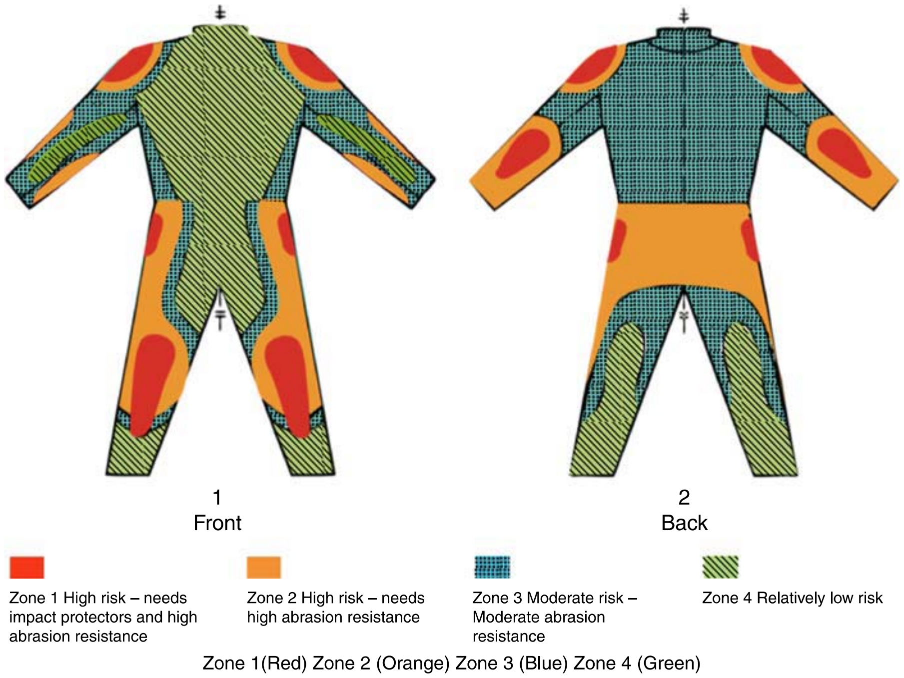


Figure 1. Zone positions on a motorcycle riders suits according to European Standards

Source: EN 13595-2 (2002)

for Level 1 and 7.0 s for Level 2. The same standard also assesses abrasion resistance requirements for Level 1, as 1.8 s in Zone 3 and 1.0 s in Zone 4 and for Level 2, as 2.5 s in Zone 3 and 1.5 s in Zone 4 (Woods, 1996a, b; Varnverry, 2005; Mao, 2014).

The product development process followed for the development of protective clothing has followed an empirical approach for its construction for decades, as no kinematic human models have been, so far, used for the design, construction of protective, functional and aesthetic looking products (Meixner and Krzywinski, 2018). The result is, hence, a compromised fit that is not protective or comfortable for the motorcycle riders as it restricts their movements and increases strain and muscle fatigue. Yoo and Yoo (2012) reported that any restriction in one of the multiple joints can lead to altered movement and biomechanics of the rest of the unrestricted joints, hereby hindering the rest of the movement.

It is well established that a static 2D anthropometry fails to accurately capture the dimensions of complex 3D human form, and conventional patterns produced by 2D flat pattern methods fail to factor in the change in body shape and size during extreme body postures. Clothing of motorcycle riders needs to fit the body perfectly and support particular body parts; it is very difficult to satisfy those criteria and to achieve high fit of clothing models using only clothing size systems and convectional 2D construction methods. Hence, patterns designed by these methods yield poorly fitting garments. Conventionally, anthropometric data are used for clothing design, PPE, workstations and man–machine interfaces. Therefore, two different measuring systems are used: size charts and ergonomic standards. Size charts are the bases for clothing industry; however, size charts cannot cover the functional requirements of professional clothing and PPE. The body measurements during exercising movements (standing, sitting, kneeling, etc.) vary significantly from the measurements of size charts, which are measured in standard standing position (Loercher *et al.*, 2018).

In functional sports clothing or protective work clothing, highly dynamic and specific movements are carried out in some instances. In order to make sure that the clothing product offers an optimal fit, specific protective function and an ergonomic comfort, substantiated analysis of the body is necessary. Clothing can only protect well when it fits well, especially during motion. To ensure a good comfort and fit of motorcycle protective clothing, the complete development process is best conducted digitally, with the application of specialized CAD systems that enable 3D designing and pattern construction process on the 3D virtual human body model. The advantage offered by the 3D pattern examined in this study is that the 3D patterns generated through this process will be created directly from the 3D shape of the motorcycle rider keeping the typical body postures adapted by the motorcycle rider during the riding in consideration.

Hence, to design functional clothing for a motorcycle riders that fits well, is comfortable and does not restricts the body movement, the motion followed by the motorcyclist's body is necessary to be studied. As the body motion and poses obtained during motion need to be considered for the design and construction process to provide high functionality of motorcycle suits in both static and dynamic conditions. The objective is:

(1) to identify the typical body postures of a motorcycle rider while mounting and riding a motorcycle;

(2) use the typical postures to design a protective top and bottom garment in 3D on an animated digital human body model; and

(3) to carry out virtual fit analysis of the designed garment on the animated model.

2. Methodology

2.1 Kinematic analysis

Kinematics is the study of the motion of the body, limbs and joints that occurs during a movement. This method of analysis provides a non-invasive means of collecting objective information on joint and limb motion of the participant. For this study, kinematic analysis is used to study various body postures acquired by motorcycle riders during the act of mounting and riding a motorcycle.

2.1.1 Participants. Ten amateur male motorcyclists with average age of 26 years, mean height of 5.7 ft and mean weight of 65 kg volunteered to participate in the study. All motorcycle riders have a motorcycle riding experience of +2 years; hence, are well versed with the act of mounting and riding the motorcycle. More over the participants were habituated to frequent riding of at least 60 min daily or more prolonged weekly exposures. The participants signed written informed consent prior entering the study. All experimental procedures for this human volunteer research were performed in a controlled environment. The participants were asked to arrive at the experiment venue 30 min before the experiment started. The participants were briefed about the experiment and the act that was to be performed by them. This enabled them to feel comfortable with the environmental conditions and the experimental setup.

2.1.2 Motorcycle. Commuter or a standard type motorcycle (i.e. one has an erect posture) was used for the experiment. A motorcycle was fixed on its side stand at a fixed location and the motorcycle riders were requested to approach the motorcycle, mount its seat and obtain the riding posture (Figure 2). A standing point was marked on the ground besides the motorcycle where the participant had to stop and begin mounting the motorcycle.

2.1.3 Camera. Three professional cameras (Canon D50) were stationed on a tripod at a height of 0.76 meter and at a distance of 3 meters away from the motorcycle as to record the entire movement of the motorcycle rider while he approached the motorcycle and mounted it. The motorcycle riders' act was video recorded three to four times so that the complete

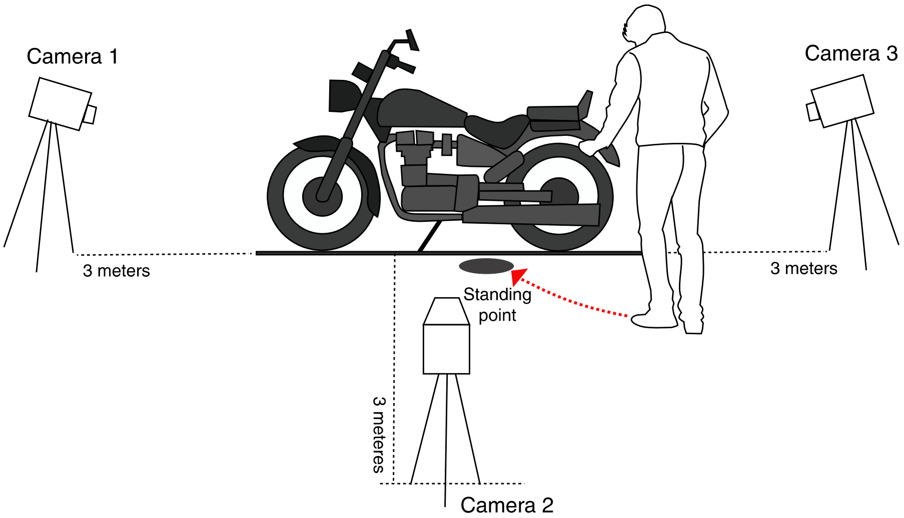


Figure 2. Experimental setup for recording motorcycle rider's kinematic motion

process is captured without any distortion. The video was recorded and later analyzed and the key steps were extracted from the whole procedure. The whole act of mounting a motorcycle took approximately 40 s to complete.

2.2 Designing a protective Jacket and trouser in 3D

2.2.1 Skinned multi-person linear (SMPL) model. A 3D human body model developed by Max Planck Institute (MPI-SMPL, 2015) (http://smpl.is.tue.mpg.de/downloads) (Loper *et al.*, 2015) was used for this study (Figure 3). SMPL is a high-quality 3D human body model that is trained from thousands of 3D scans and is capable of capturing the statistics of shape variation in the population as well as how people deform with pose. It is a parameterized

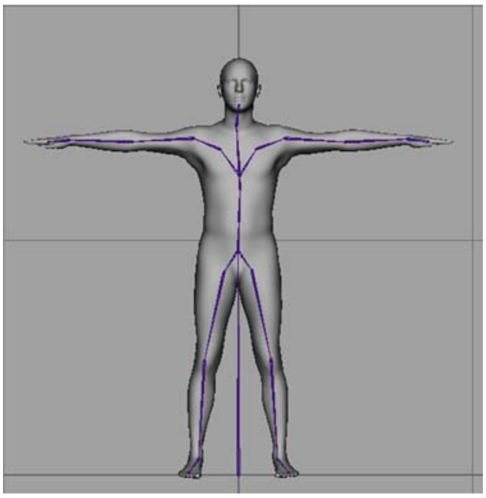


Figure 3. SMPL model by Max Planck Institute, Germany

Source: MPI-SMPL (2015)

model of naked humans that takes 72 pose and 10 shape parameters and returns a mesh with $n = 6{,}890$ vertices. The model describes the human body as a kinematic tree, consisting of segments that are linked by 19 movable joints. This model was selected for the study as it is capable of being animated in any kind of pose and realistically representing soft tissue deformations. It produces posture dependent soft tissue and muscle deformations, which make the 3D model close to realistic.

2.2.2 Softwares. MAYA 3D (Autodesk MAYA 3D, 2018) was used to animate the SMPL model into the desired postures and export the 3D model as .obj (3D model format). The polygonal surface deformations that occurred during posture animation were corrected using 3D Systems Geomagic Studio 12 (Lectra Systems Modaris, 2012) at ITM, TU Dresden. The *NURBS* surface, thus, obtained was used for designing the garment pattern using Designconcept3D (Lectra Systems DesignConceptAuto, 2013) by Lectra Systems. Virtual fit analysis for jacket and trouser was conducted using Modaris by Lectra.

3. Results and discussion

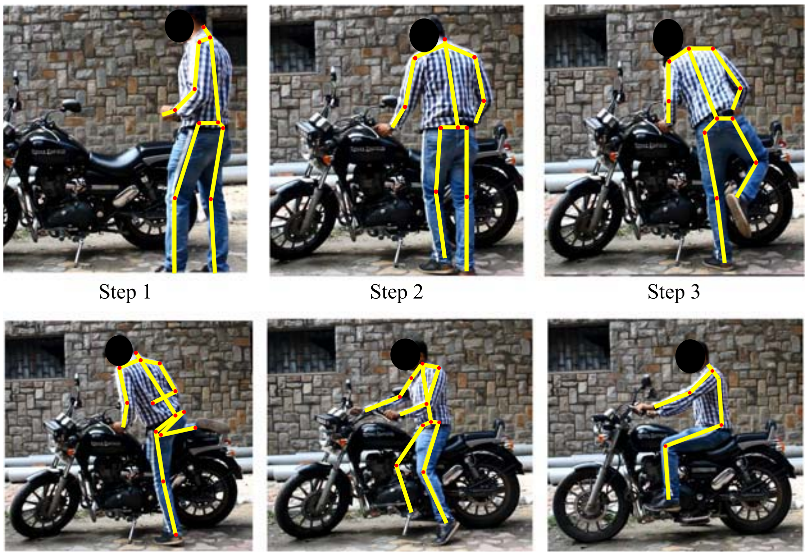
3.1 Kinematic analysis

An experiment was conducted in which the steps used by a rider to obtain the posture for mounting a motorcycle were studied. Six major steps were identified (Figure 4). Images of each step were extracted from the video recording:

(1) Approaching the motorcycle – when the rider approaches the motorcycle he comes to a halt and attains a fundamental posture.

(2) Holding the handle – the motorcycle rider raises his/her hand to hold the handle bar, which acts like a pivotal point. Then, the rider slightly twists toward his/her left side to lift their leg to begin the mount.

(3) Lifting the leg – holding the handle bar gives stability to the rider. The rider bends slightly forward and lifts his/her right leg.



Step 1 Step 2 Step 3

Step 4 Step 5 Step 6

Figure 4. Steps involved in mounting a motorcycle

(4) Swinging the leg – the rider swings across his/her right leg over the motorcycle seat.

(5) Both feet on the ground – after the right leg has crossed over the motorcycle seat, the rider plants both his/her feet on the ground. Simultaneously, he/she moves his/her right hand to hold the handle grip. Now with both the riders' feet on the ground and both of his/her hands holding the handle grip, the rider straightens the handle of the motorcycle and removes the side stand.

(6) Ready go position – the rider obtains the final position.

All the joint movements involved in this act are represented in Figure 5. All the body movements happened in the inferior and superior plane. A red dot was used to mark the joints at the neck, shoulder, elbow, hip and knee of the motorcycle rider, which were linked by straight lines that represent the riders' limbs. These limb lengths helped in identifying abduction, flexion and extension at the various joints. Neck joint was marked as the highest point and the ankle on the motorcycle rider formed the lowest point (Figure 5). Both these points were used to study the displacement of the body during the complete cycle. Marking the limb lines is important, as they will later be used for pose adaptation on the 3D model.

Four body poses Step 1, Step 3, Step 4 and Step 6 (encircled in orange box) were identified as the typical body poses of a motorcycle rider. Step 1 is the fundamental pose, which the motorcycle rider adapts when not on the motorcycle, it is important for the garment designed to fit well in this posture as otherwise it will negatively impact the aesthetics of the wearer. Step 4 is the maximum displaced body posture, which significantly strains the body of the motorcyclists because of an extreme angle formation in both the knee and elbow joints. Step 6 (longest duration) is the most strenuous positions of the mounting motion as in both the positions the stress on the rider's body is maximum. The rider throughout the process of riding the motorcycle maintains this posture; hence, it is important for the clothing to offer minimum stress and strain during this posture.

3.2 Mapping the identified typical body postures on SMPL model

The next step was to map the identified typical postures derived from the video recordings of the motorcyclist on to the 3D model. For this, Autodesk MAYA 3D, 2018 was used. The images of the typical poses were kept as template for the SMPL model and the joints of the

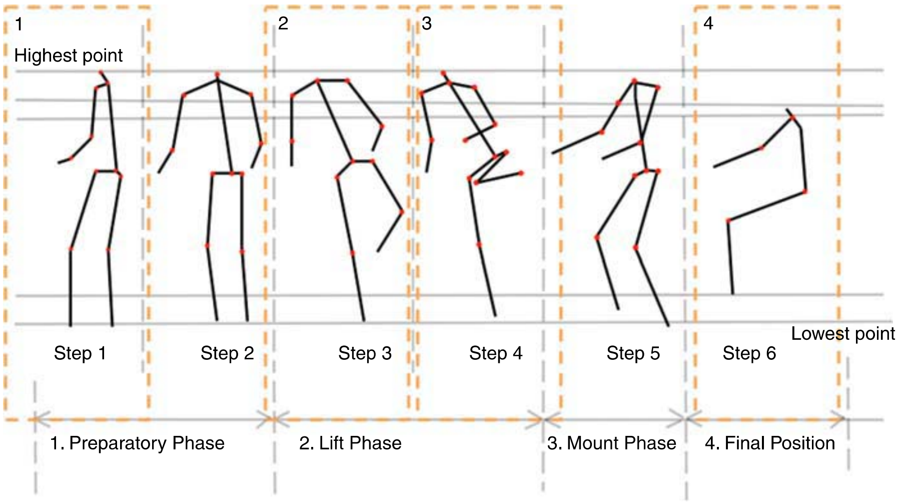


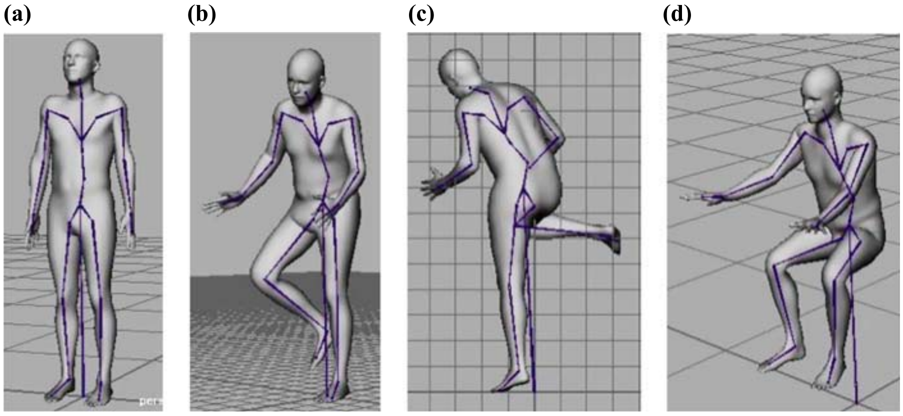
Figure 5.
Kinematic analysis of a motorcycle rider

3D model were moved and rotated along X-axis, Y-axis and Z-axis to form each pose. The animation was created with 100 frames of transition from the fundamental posture to dynamic posture, for each dynamic pose, in order to achieve a smooth body movement (Figure 6). So after the alignment in the right position of the template, the surface was transformed into an editable mesh for each of the four body postures.

After acquiring the different postures, the animated forms were completed using Geomagic Studio 12 (Figure 7).

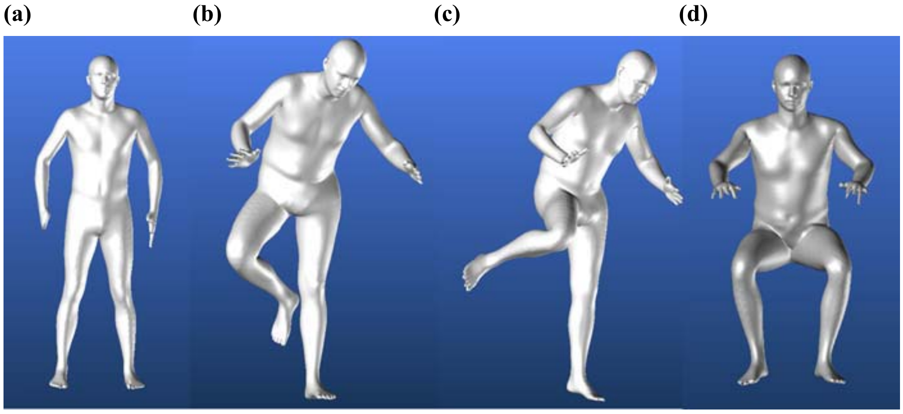
3.3 *Garment pattern construction in 3D*

Protective zones as prescribed in the European Standard for development of motorcycle protective clothing (EN 13595) were first mapped on the 3D form. Zone 1 (red) and Zone 2 (orange) are high injury risk zones and, hence, protection is a foremost priority here, whereas Zone 3 (blue) and Zone 4 (green) are moderate injury risk zones and, hence, can be used to provide comfort (ventilation vents, mesh, etc.) and mobility feature for the wearer.



Notes: (a) Static posture; (b) Posture 1; (c) Posture 2; (d) Posture 3

Figure 6. Animating the postures on SMPL model



Notes: (a) Static posture; (b) Posture 1; (c) Posture 2; (d) Posture 3

Figure 7. NURBS surface generation

Patterns for jacket and trouser were drawn directly on the 3D forms by drawing and creating pattern lines directly on the body surface in the software Designconcept3D (Figure 8). This method unifies garment design and construction process and helps the designer to create and modify garment patterns by precisely positioning them at specific location and also helps them to simultaneously visualize the final pattern shape on the body surface.

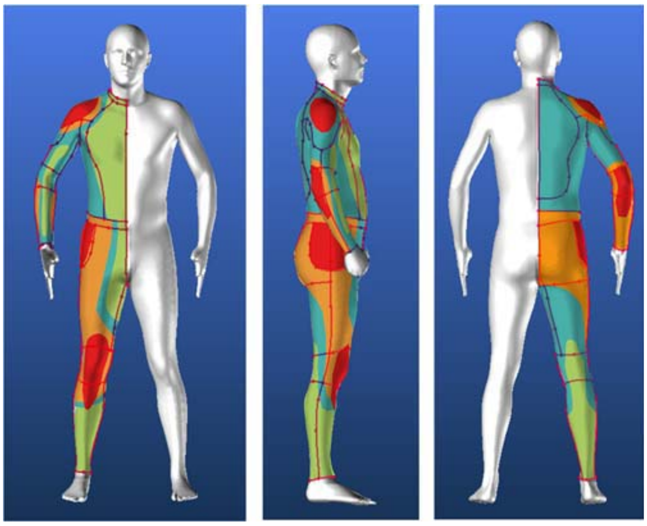
Garment pattern is designed keeping the four zones into consideration. Seams have been avoided in Zone 1 and Zone 2 to prevent seam burst or seam failure because of the possibility of a direct impact in these zones. Raglan sleeves were provided in the jacket so as to remove the seam from the shoulder and armhole area. The raglan sleeve will provide a better mobility of upper extremities and also allow seamless insertion of the shoulder protectors into the jacket for impact protection. The kinematic analysis showed that the elbow, knee and lower back region were subjected to excessive strain during the process of mounting and riding a motorcycle. Provision for incorporating an articulated elbow, knee and lower back was, therefore, made in the pattern. The final pattern was mapped on all the four postures. A mesh was generated on the line constructions. The mesh divides the 3D model's surface into many small 3D surfaces.

3.4 Pattern flattening

2D patterns were created with the help of automatic 3D flattening procedure that separates discrete 3D surfaces and transforms it into 2D cutting parts. There were a total of 20 patterns for the bottom and 22 patterns for the top garment. The process was repeated for all four postures (Figure 9). The patterns obtained are replicating the natural curves of the body in 3D, which is not possible to achieve using 2D garment pattern construction methods.

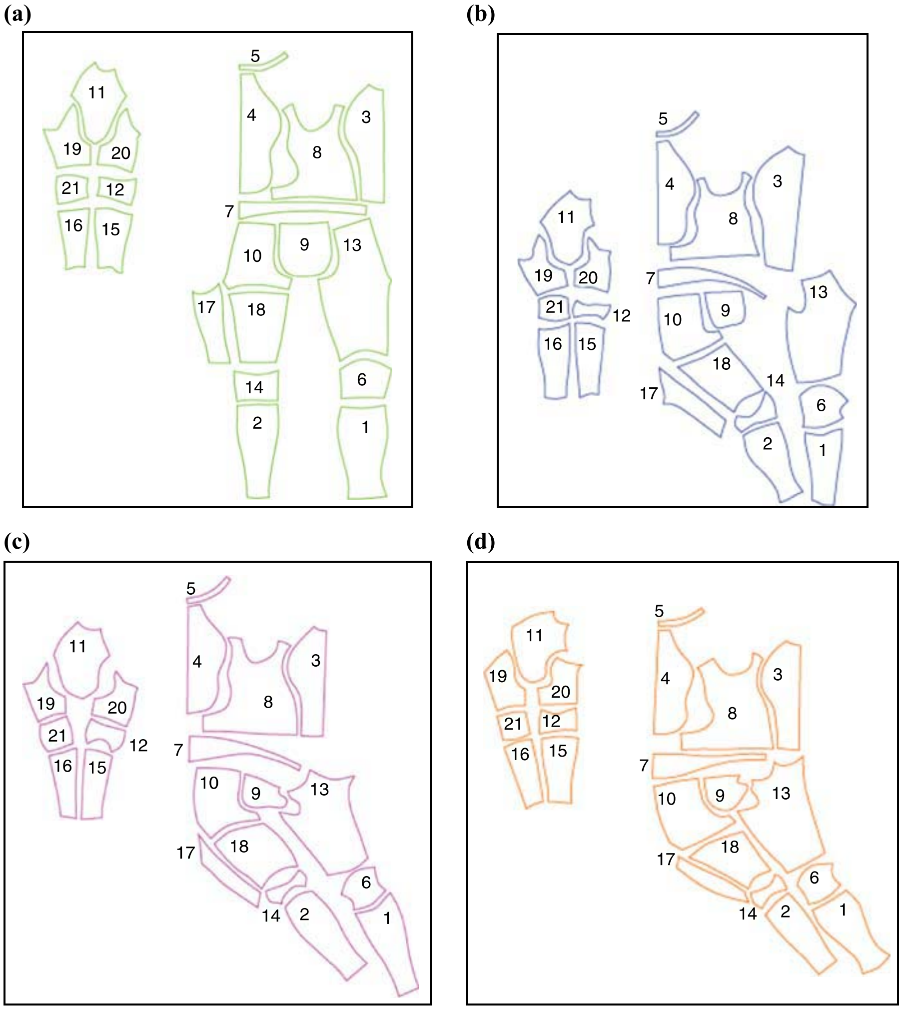
3.5 Comparison of 2D patterns

Understanding the changes in the measurement of the body during movement is complex in nature and it cannot be solely studied using basic anthropometric measurements. The body



Notes: Zone1 – red and Zone 2 – orange, and comfort features for Zone 3 – blue and Zone 4 – green

Figure 8.
Design features for protective zones



Notes: (a) Static posture; (b) Posture 1; (c) Posture 2; (d) Posture 3. 1 – front leg; 2 – back leg; 3 – front chest; 4 – back chest; 5 – collar; 6 – front knee cap; 7 – waist band; 8 – side chest; 9 – waist side; 10 – back hip; 11 – shoulder cap; 12 – back elbow; 13 – front thigh; 14 – back knee; 15 – back hand; 16 – front hand; 17 – inner thigh; 18 – back thigh; 19 – front arm; 20 – back arm; 21 – front elbow

Figure 9.
Pattern flattening

surface area deforms and its measurements change with every posture and motion exhibited by a rider during the act of mounting and riding a motorcycle. While moving the rider stretches their hand and legs, and hence, the garment on the body too moves along and if the movement is not built into the garment pattern it will cause pressure and hinder the movement of the body. Hence, it is very important to accommodate dimensional body changes while designing and constructing functional clothing. The garment, thus designed, will need additional ease allowance and stretch panels on specific body regions to accommodate these changes in measurements.

Measurement changes at various locations on the body are presented in Figure 10. It shows the difference between values measured in four postures obtained by the motorcycle rider caused by the movement of different parts of the body. This change in measurement of the body in different postures cannot be accurately captured by 2D anthropometric body measurement techniques. The garment pattern designed without incorporating the required ease will yield poorly fitted garments. Hence, it is critical to determine changes in body measurements and incorporating the appropriate ease required in the garment pattern for design of functional clothing for motorcycle riders. The deformation of each pattern was studied and compared for all the four postures (Figure 11).

The mean of each of the lengths was calculated and compared with the Static posture. Lengths with maximum elongation and compression were recorded for each of the pattern. Pattern lengths closest to the mean were selected. The selected patterns of each of the pose are encircled in green. The selected patterns ranged from all the four body postures (Figure 12). It can be noted from the 2D garment patterns that maximum number of selected patterns belong to the Static posture (11 out of 21 patterns) (Figure 12) that is a positive result as motorcycle protective clothing should fit the rider well in the standing posture to justify the aesthetic value. Six of the patterns (Hip, side hip, front thigh, front leg, front arm and front chest) were selected from the Posture1 and three of the patterns (Collar, Elbow and waistband) have been selected from the Posture 3 and one (back knee) is selected from the Posture 2.

As the patterns were designed on the 3D form based on the protective zoning, it can be noticed that the patterns obtained on flattening are complex shaped with double curvatures. Some of the pieces may look skewed and odd shaped and do not truly conform to the garment pattern shapes obtained through the conventional garment pattern making technique. Before joining the patterns and performing fit analysis, the pattern correction and seam truing were undertaken to match each seam.

The fit simulation for the pattern was checked in Modaris (Figure 12). The position of particular cutting parts was predefined against the body surface for preforming fit simulation. Cylindrical curvature was predefined depending on the position of the pattern on the body. During the fit simulation, 2D garment patterns were transformed into 3D shape on the 3D body. By sewing the patterns, we can see in the end the necessary modifications for the top and bottom in different positions. After the fit simulation, it was noticed that the waistband was loose that can be elasticated and the extra ease generated in the 3D pattern can be accommodated during the final garment fit.

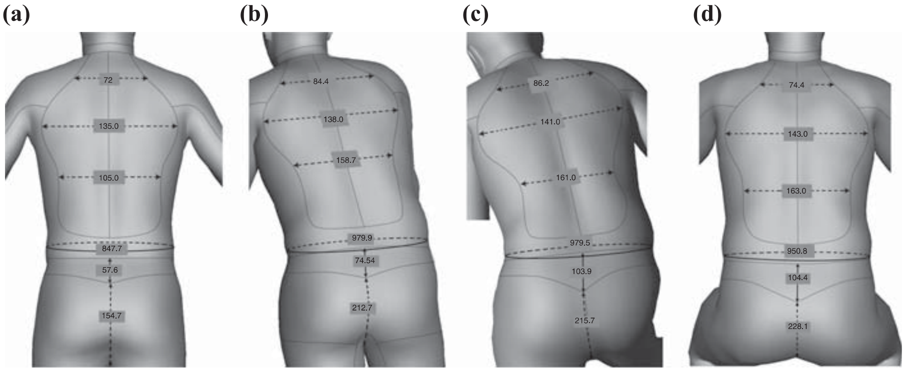
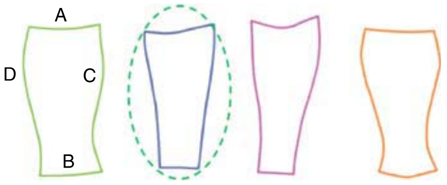


Figure 10.
Measurements on model

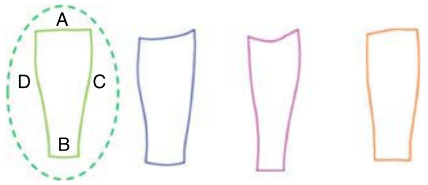
Notes: (a) Static posture; (b) typical Posture 2; (c) typical Posture 3; (d) typical Posture 3

1. Front leg



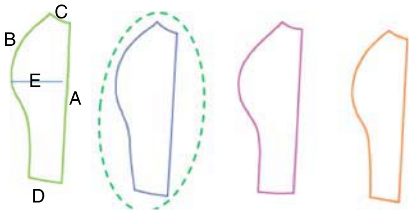
	Static	P1	P2	P3	Mean
A	156.05	177.74	178.38	159.94	168.02
B	84.27	115.16	91.06	112.49	100.74
C	362.44	356.18	347.89	350.77	354.32
D	357.00	356.39	348.92	339.61	350.42

2. Back leg



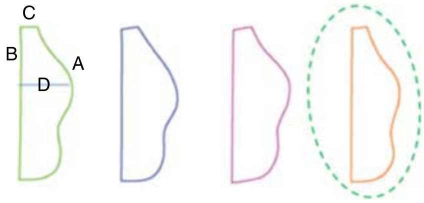
	Static	P1	P2	P3	Mean
A	171.88	177.08	174.78	159.06	170.70
B	357.76	354.26	368.13	350.34	357.62
C	149.15	125.19	107.02	112.53	124.47
D	362.44	336.26	348.91	339.60	346.80

3. Front chest



	Static	P1	P2	P3	Mean
A	444.15	421.33	431.43	444.61	435.38
B	501.42	497.72	504.29	507.87	502.82
C	59.54	60.80	59.48	61.76	60.39
D	87.54	86.58	84.28	85.39	85.94
E	148.66	152.78	153.91	150.83	151.54

4. Back chest

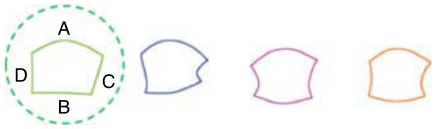


	Static	P1	P2	P3	Mean
A	562.49	575.07	572.80	570.00	570.09
B	436.90	436.29	436.05	436.75	436.49
C	47.50	47.37	47.06	47.00	47.23
D	135.40	137.00	137.00	143.00	138.10

5. Collar

	Static	P1	P2	P3	Mean
A	191.19	192.48	196.67	194.61	193.73
B	205.36	211.86	215.26	211.26	210.93
C	20.96	20.68	20.90	20.95	20.87
D	20.96	20.96	20.60	20.90	20.85

6. Front knee cap

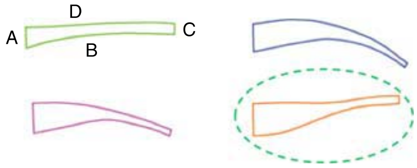


	Static	P1	P2	P3	Mean
A	169.28	182.88	179.53	163.06	173.68
B	119.46	101.43	121.55	108.42	112.71
C	219.82	230.03	229.32	205.63	219.70
D	114.76	134.24	102.10	101.10	113.05

(*continued*)

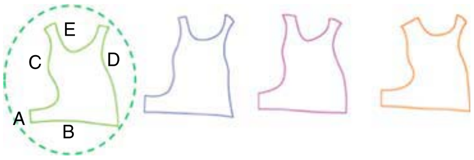
Figure 11.
Comparison of the 2D pattern for all four postures based on their degree of compression and elongation

7. Waist band



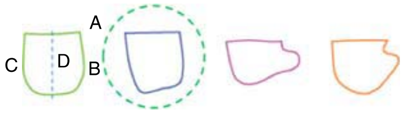
	Static	P1	P2	P3	Mean
A	57.60	74.54	103.88	104.36	61.59
B	429.15	471.26	466.72	479.88	464.50
C	30.78	12.86	19.61	25.67	14.73
D	423.87	489.89	489.73	475.42	469.72

8. Side chest



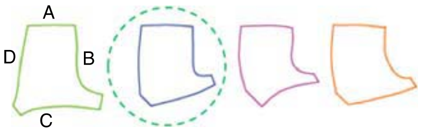
	Static	P1	P2	P3	Mean
A	45.31	56.25	65.03	66.88	58.36
B	423.87	489.33	489.60	475.42	469.55
C	319.79	308.63	321.98	312.46	315.71
D	370.87	350.74	348.11	391.07	365.19
E	280.23	264.69	261.06	260.07	266.51

9. Waist side



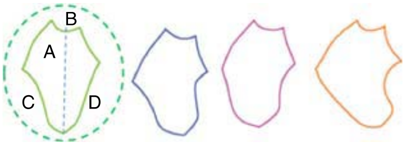
	Static	P1	P2	P3	Mean
A	158.35	157.51	155.04	150.63	155.38
B	228.57	205.00	184.56	203.15	205.32
C	154.70	212.65	215.65	218.09	200.27
D	172.92	145.99	114.98	144.59	148.59

10. Back hip



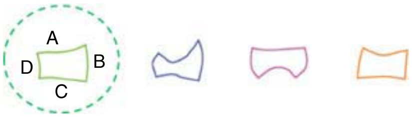
	Static	P1	P2	P3	Mean
A	134.51	175.96	183.40	186.71	170.14
B	154.70	212.65	215.65	228.09	167.98
C	228.40	227.76	228.38	241.90	231.61
D	227.81	236.55	229.23	245.84	234.85

11. Shoulder cap



	Static	P1	P2	P3	Mean
A	321.98	321.01	322.10	322.69	321.94
B	81.01	90.14	94.14	83.42	87.16
C	231.28	232.97	231.61	263.15	239.75
D	234.60	225.94	228.60	225.60	228.68

12. Back elbow

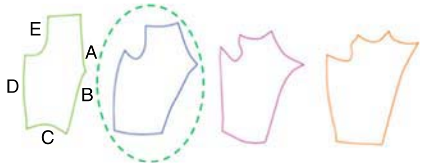


	Static	P1	P2	P3	Mean
A	121.84	139.56	124.50	127.49	128.34
B	106.80	119.21	95.81	96.83	104.66
C	125.08	127.67	121.82	120.12	123.67
D	73.37	102.49	73.38	95.55	86.19

Figure 11.

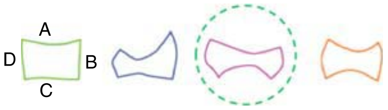
(*continued*)

13. Front thigh



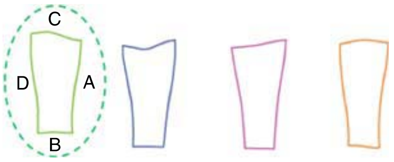
	Static	P1	P2	P3	Mean
A	243.15	210.81	208.45	175.00	209.35
B	276.22	297.56	296.44	319.00	297.30
C	182.90	205.65	194.46	189.03	193.01
D	228.57	297.68	276.21	250.00	263.11
E	228.57	205.00	179.56	176.61	197.43

14. Back knee cap



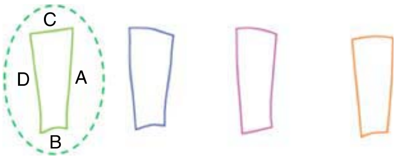
	Static	P1	P2	P3	Mean
A	114.76	124.24	102.10	101.27	110.59
B	156.11	177.77	175.70	159.96	167.38
C	119.46	91.43	118.55	108.42	109.46
D	178.44	199.99	188.53	158.79	181.43

15. Back hand



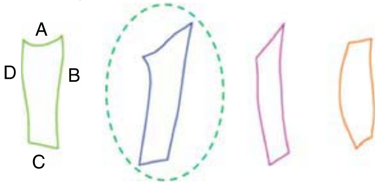
	Static	P1	P2	P3	Mean
A	231.94	239.19	224.76	219.62	228.87
B	97.02	95.81	88.72	99.34	95.22
C	125.08	127.67	121.82	120.12	123.67
D	217.54	213.19	211.11	212.12	213.49

16. Front hand



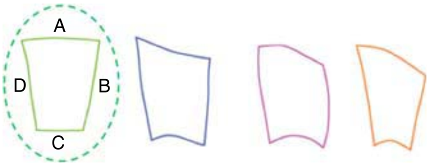
	Static	P1	P2	P3	Mean
A	231.94	239.19	227.78	226.62	231.38
B	74.54	83.63	90.55	75.54	81.06
C	125.08	127.67	121.82	120.12	123.67
D	217.54	213.19	211.11	214.125	213.99

17. Inner thigh



	Static	P1	P2	P3	Mean
A	110.20	151.96	132.92	90.03	121.27
B	296.62	369.26	335.94	343.04	336.21
C	77.05	76.28	52.37	46.48	63.04
D	276.22	297.56	296.44	319.00	297.30

18. Back thigh

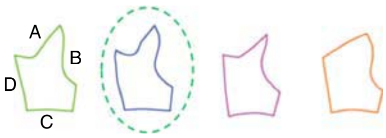


	Static	P1	P2	P3	Mean
A	228.40	227.76	228.38	241.90	231.61
B	266.92	257.71	232.39	221.71	244.68
C	136.57	164.49	187.95	126.38	155.84
D	266.61	300.45	275.15	286.95	282.29

(*continued*)

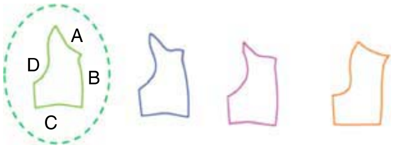
Figure 11.

19. Front arm



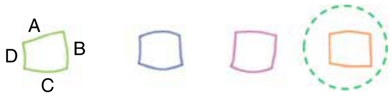
	Static	P1	P2	P3	Mean
A	167.96	156.80	164.65	146.34	158.93
B	165.83	171.00	162.12	174.75	168.42
C	121.84	139.56	124.50	127.49	128.34
D	156.62	171.16	159.03	170.27	164.27

20. Back arm



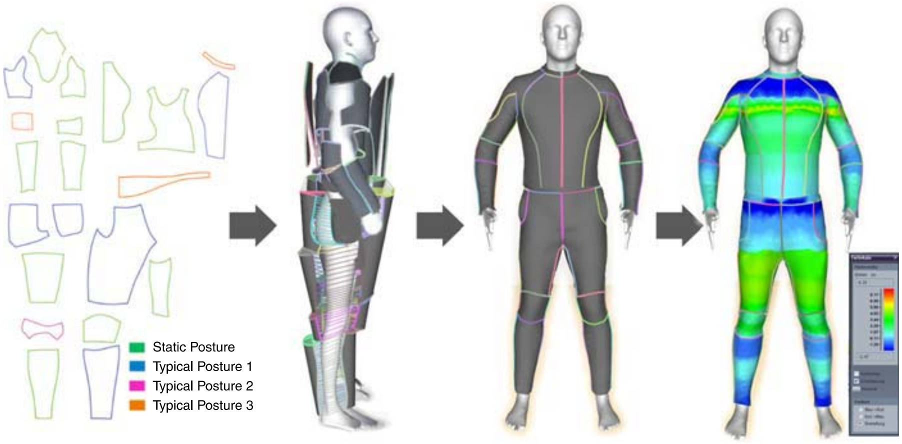
	Static	P1	P2	P3	Mean
A	118.20	119.10	120.29	112.70	117.57
B	156.62	171.66	162.12	170.27	165.16
C	141.12	144.26	155.00	145.02	146.35
D	189.72	176.09	179.73	179.26	181.20

21. Front elbow



	Static	P1	P2	P3	Mean
A	141.12	144.26	155.00	145.00	146.34
B	73.37	111.49	73.37	95.55	88.44
C	145.97	157.99	152.99	156.59	153.38
D	106.80	109.21	85.81	76.87	94.67

Figure 11.



2D flat garment patterns Fit simulation 3D prototype Fit analysis

Figure 12.
3D simulation and fit analysis of a motorcycle suit

4. Conclusion

The aim of this study was to develop a new and efficient way for creating ergonomic clothing for motorcycle riders according to the motorcyclist’s typical body motions. The motorcycle riders wear multiple layers of clothing while riding a motorcycle to protect them in case of an accident. Multiple clothing layers worn by the rider may restrict the riders body movements and add on to the fatigue levels of the motorcycle rider that might even lead to motorcycle accidents putting the life of the rider at risk. Hence, there is a need to develop ergonomic clothing garments for motorcycle riders, that fit well, are comfortable and do not restricts the riders body movements.

Clothing requirements for functional clothing is difficult to address using the conventional ready-to-wear garment construction methods. Static 2D anthropometry fails to accurately capture the dimensions of complex 3D human form and conventional patterns produced by 2D flat pattern methods fail to factor in the change in body shape and size during extreme postures. Hence, patterns designed by these methods yield poorly fitting garments. The development of virtual 3D garment pattern using digital human body models is more familiar these days but they have not been used till date, to develop specialized garments like motorcycle protective clothing. Therefore, in this study, virtual, 3D human body models were developed in selected dynamic poses using kinematic analysis of a motorcycle rider to identify the typical poses. A digital 3D human body model SMPL was used as the base model for this study.

The proposed method of garment development by using digital human body models has proved to be efficient in obtaining requisite body posture of the motorcycle riders. In the end, creating the garment and the 3D–2D flattening stratagem gave us a good perspective upon the adjustment that has to be done in creating ergonomic jacket and trouser for motorcycle riders.

5. Future work

Although more research is necessary in this area but the animation of the human body in the 3D program has proven to be efficient. There is a need to study and analyze the amount of stress imparted by the clothing on the motorcyclist's body in this position. The 3D–2D garment pattern flattening methods manifested out a positive view about the dimensional changes the fabric undergoes during dynamic body postures. The garment patterns obtained from this research are tight fit garment with no ease incorporated into the patterns. The future work will be to add appropriate ease to each of the garment pattern and build a physical prototype with appropriate fabric and materials to test the garment on a motorcycle rider.

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Corresponding author

Deepti Gupta can be contacted at: deeptibgupta@gmail.com