Kim *et al. Fash Text (2019) 6:33*
https://doi.org/10.1186/s40691-019-0187-z

Fashion and Textiles

REVIEW

Open Access

Standardization of the size and shape of virtual human body for apparel products

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Abstract

International virtual human body (VHB) standards from the International Organization for Standardization (ISO) specifically used in virtual garment systems in the apparel field, as suggested in ISO/TC 133/WG 2 (Working group 2), contain fundamental content regarding definitions of terms, attributes of composition, and the expression and alteration of VHBs. As the first attempt in the series of international standards dealing with VHBs, this study has dealt with fundamental content related to VHB size. Additional standardization is required to allow the size and shape of VHB to be reproducible. Therefore, this study suggests academic and industrial requirements from the perspective of standardization to identify and solve issues regarding the reproduction of human bodies in terms of VHB size and shape. This study is meaningful in that it provides an overview of current VHB standardization efforts, related proceedings, and additionally required assignments. The suggested industrial and academic requirements are anticipated to be helpful in the systematic development and utilization of VHB and general standardization work.

Keywords: Standardization, Digital fitting, Virtual human body, Body size, Body shape

Introduction

Digital technology has been continuously evolving since it emerged in the 20th century and has a significant influence on society at large. A significant amount of digitalized information is now accessible. When novel digital devices are introduced, they are quickly adopted into our daily lives. Our society is currently in the stage of cyber space, which is one of the informatization developing phases (The Korean Society for Journalism & Communication Studies, and Korean Sociological Association 1998). In other words, virtual space is on the rise while temporal and spatial boundaries are weakened, as is characteristic of the cyber space stage (Lee 2003a, b). In response to real culture, cyber culture develops from a virtual community and may have influence on real society. People may create digital human models as an alternative of actual human bodies, while simulating them in the virtual space such as virtual reality (VR) and utilizing them in research or industry (Park et al. 2018).

Currently utilized digital human models in various fields have different structural and functional features depending on their purpose. In order to apply digital human models to actual human bodies, certain requirements must be fulfilled to ensure that the characteristics of digital human models reflect actual human bodies. As for virtual human body (VHB) in the virtual garment system, the features used to determine garment fit must be similar with those of actual human bodies in consideration of the distinct characteristics in the apparel industry. In the apparel industry, "VHB" is relevant to an intermediate form between a "simple shape model" that indicates skin and body type and a "multi-body model" that has moveable bones or joints for body pose and motion (Korean Agency for Technology and Standards 2013).

The most urgent assignment currently required of VHB in the apparel industry regarding the reproduction of human bodies is to ensure reproducibility in the size and shape. Digital fitting technology has emerged to solve the issue of garment fit in e-commerce. However, digital fitting technology has been unable to solve the current issue related to garment fit since virtual garment systems do not exhibit reproducibility of VHB size and shape and can even lead to confusion in consumers' garment fit evaluation (ISO 18825-1 2016b). Therefore, it is urgent to prepare standards as a guideline to ensure that VHB size and shape is reproducible.

Considering the necessity of VHB standardization, our researchers and the Korean Agency for Technology and Standards (KATS) have begun to implement international VHB standards in the apparel industry in 2010. Starting from the working group (WG) 2 (Digital Fitting) organized in ISO/TC 133 (Clothing) and the New Work Item Proposal (NWIP) submitted in 2011, the proposal has finally been approved as an international standard (ISO 18825-1 and ISO 18825-2) by ISO in 2016 after passing the Working Draft (WD), Committee Draft (CD), Draft International Standard (DIS), and Final Draft International Standard (FDIS) stages.

The objective of this study is to review current VHB standards and seek solutions for current issues related to VHB standardization. Specifically, this study provides a summary of processes and major content related to ISO 18825-1 and ISO 18825-2 in ISO/TC 133/WG 2. Since current international standards contain only fundamental content, additional work is required on VHB standardization in the apparel industry. Therefore, based on the discussion by the experts who suggested ISO 18825-1 and ISO 18825-2 during the period of the project, this study approaches issues of VHB size and shape reproducibility in the apparel industry. This seemed to be an urgent issue in the perspective of standardization to solve the aforementioned issues.

Emergence of digital fitting technology

Issues of garment fit in online shopping

There are limitations surrounding the online purchase of items since people are required to make a decision only by predicting characteristics of apparel products indirectly through their screen, without physically touching and wearing them (Tak and Kim 2006). Jang (2004) indicated that appropriate garment size was one of the most important characteristics of purchasing clothes, both online and in-store. He added that it was also a hindering factor in online shopping. Kim and Choi (2002) explained that inappropriate garment size was the second most significant factor of dissatisfaction behind the quality of materials when purchasing clothes online or through telemarketing. In addition, it was also the biggest factor in returning items to a store.

Current online shopping malls have been attempting to solve the issue of garment fit by suggesting photographs or measurements of the apparel products (Lee 2003a, b).

However, it is inconvenient for consumers to make a rough guess as to whether certain clothes are suitable to them by evaluating a photograph of a model with a skinny and idealistic body type. It is also difficult for consumers to manually measure clothes with a ruler in order to confirm that the clothes are manufactured using the measurements table proposed by the seller. In addition, they tend to be uncertain if their chosen apparel products are actually suitable to their bodies. Therefore, the aforementioned methods are limited. An issue of whether certain apparel products fit consumers' bodies remains in the online apparel industry.

Emergence of virtual garment system

Establishing a shopping environment in which consumers are able to wear certain clothes in online virtual stores has been suggested to secure trust from consumers in order to supplement weaknesses in online shopping (Tak and Kim 2006). Efforts from many developers have produced virtual garment systems such as "Runway" from Optitex, "V-stitcher" from Browzwear, "Modaris 3D Fit" from Lectra, "i-Designer" from Technoa, "i-Virds" from i-Omni, "Clo 3D" from CLO Virtual Fashion Inc., and "DC Suite" from Digital Clothing Center of Seoul National University (Park and Kim 2008; Lee 2007).

Efficiency of digital fitting technology and utilization case studies

Efficiency of digital fitting technology

Digital fitting technology makes it feasible for online clothes to be applied on VHB, coordinate apparel products, and observe products from the preferred angle using 360° rotation by producing VHB of the similar or same sizes as consumers (Lee 2009). In addition, virtual garment systems are equipped with a function for consumers to intuitively and quantitatively evaluate appropriate garment size by providing ease allowance as well as garment pressure when virtually fitting them (Clo Virtual Fashion Inc. 2012).

Suh and Oh (2006) indicated that digital fitting technology reduced perceived risk but enhanced shopping satisfaction by providing the function for evaluating the appearance and size of a virtual garment. You and Lee (2010) reported that digital fitting was effectively suggested in the online sales of items with high perceived risk compared with other proposed clothing coordination methods. They also stated that it was desirable to suggest photos and digital fitting at the same time to enhance consumers' shopping experience.

Park and Choi (2013) indicated that the application of this technology in apparel manufacturing is expected to reduce time, cost, and effort in the planning stage. Digital fitting technology is a valuable alternative for the production of actual garments as three dimensional images of the designed garment could be inspected in advance in a short amount of time. Park and Kim (2008) expected to create a new market from a new paradigm as customization becomes increasingly feasible so long as digital fitting technology is successfully commercialized. Lee (2010) expected that digital fitting technology could relieve producers' time, manpower, and stock burdens. At the same time, it is possible to easily pursue a design preferred by consumers by sharing objective information related to design and garment fit. Therefore, digital fitting technology is anticipated to bring about developmental changes in the whole apparel industry.

VHB development and digital fitting technology utilization case studies

Studies on the development of digital human models have been actively conducted in the engineering field and in the apparel industry (Yang et al. 2011; Zhu et al. 2013; Kim and Park 2004; Li and Chen 2009) as well as virtual garment simulation (Li et al. 2010; Wang et al. 2011; Gröller and Szirmay-Kalos 2006; Zhong and Xu 2009). Most studies that utilized digital fitting technology seem to positively assume the function of virtual garment system without providing a sufficient review of related issues. Lim (2011a, b, 2013) and Lee and Lee (2012) utilized digital fitting technology for garment pattern making. Park and Lee (2012) and Do (2008) utilized it for fitting evaluation. In addition, Hong and Suh (2012) and Cha and Kang (2013) also utilized it for pattern comparison, and Roger (2011) applied the grading method to virtual garments in garment research.

Standards related to VHB

Standards related to the digital human model in other fields

According to standards of the digital human model in other fields regulated by ISO, ISO/IEC 19774 (2006) in the ISO/IEC JTC 1 dealt with a systematic method for representing humanoids in a network-enabled 3D graphics and multimedia environment. Additionally, it regulated the abstract form and structure of humanoids. ISO/IEC 19775-1 (2013) regulated file formats for data exchange, dealing with a software system to integrate network-enabled 3D graphics and multimedia (Paul and Wischniewski 2012). ISO 15536-1 (2005) in the ISO/TC 159 regulated their anthropometric and biomechanical properties, dealing with general requirements for the design and development of computer manikins, body templates, and manikin systems (Table 1).

Standards related to body measurement

Standards regulating VHB by focusing on the apparel industry have been nonexistent thus far. However, there are standards applied to body measurement to deal

Table 1 Existing standards related to VHB

Section	Standard no. (year)	Title
Standards related to digital human models in other fields	ISO/IEC 19774 (2006)	Information technology—computer graphics and image processing—humanoid animation (H-Anim)
	ISO/IEC 19775-1 (2013)	Information technology—computer graphics, image processing and environmental data representation—extensible 3D (X3D)—part 1: architecture and base components
	ISO 15536-1 (2005)	Computer manikins and body templates—part 1: general requirements
Standards related to body measurements	ISO 7250-1 (2008)	Basic human body measurements for technological design—part 1: body measurement definitions and landmarks
	ISO 15535 (2006)	General requirements for establishing an anthropometric database
	ISO 20685 (2010)	3D scanning methodologies for internationally compatible anthropometric databases
	ISO 8559 (1989)	Garment construction and anthropometrics surveys—body dimensions

with VHB size and shape. According to standards applied to body measurements in the field of ISO/TC 159 (Ergonomics), ISO 7250-1 (2008) provides a description of anthropometric measurements. This can be used as a basis for comparing population groups for technological design. ISO 15535 (2006) provided necessary information, such as characteristics of the user population, sampling methods, measurement items and statistics, specifying general requirements for anthropometric databases, and their associated reports that contain measurements. ISO 20685 (2010) dealt with protocols for the use of 3D surface-scanning systems in the acquisition of data for human body shape and measurements. For standards related to body measurements in the apparel industry, ISO 8559 (1989) for garment construction and anthropometric surveys-body dimensions in the ISO/TC 133 regulated the location and taking of body dimensions. This applies to all items of clothing for men, women, and children. Body dimensions and characteristics in the ISO 8559 (1989) used for actual garments can be considered to enhance the reproducibility of the size and shape of VHB (Table 1).

Proceedings and major content of international VHB standards in the apparel field

International standards procedures

Our research team and KATS have instigated the activities necessary to enact international standards on VHB in the apparel industry in 2010 and obtained final approval in 2016. The procedures undertaken to establish ISO standards for VHB in the ISO/TC 133/WG 2 are as follows.

A NWIP case "Vocabulary and Terminology used for the Virtual Human Body" (N0031) was first submitted to the International Organization for Standardization in 2011. In the ISO/TC 133 plenary meeting in the apparel industry held at Pretoria, South Africa, from July 19 to 22 in the same year, "ISO/TC 133 (Clothing) WG 2 (Digital Fitting)" was approved to be constituted. According to the result of voting on one case of the NWIP, approval was granted from more than five P-member countries. At this point, experts in Korea acquired convenorship. In the ISO/TC 133 meeting held in Seoul, Republic of Korea, from September 17 to 21 in 2012, the remaining six cases (N0056, N0057, N00058, N0059, N0060, and N0061) were listed in the NWIP. According to the result of the vote, the adoption of five NWIPs was agreed upon by more than five P-member countries. In the ISO/TC 133 meeting held in Paris, France, from May 27 to 31 in 2013, the integration of six drafts to two drafts was decided. Parties agreed to list these two drafts as the CD as it was relevant to the committee stage beyond the WD at the preparatory stage. On October 22, 2013, N0031 "Part 1: Vocabulary and Terminology used for the Virtual Human Body" and N0056 "Part 2: Vocabulary and Terminology used for Attributes of the Virtual Human Body" were approved as the CD. They were also approved as the DIS at the enquiry stage on December 19, 2014, and July 25, 2015, respectively. After passing the FDIS (Final Draft International Standard) at the approval stage, N0031 (ISO 18825-1) and N0056 (ISO 18825-2) were finally approved as ISO international standards at the publication stage on July 13, 2016 and July 5, 2016, respectively.

Major content of international standards

Definitions of fundamental terms of digital fitting technology

VHB standards in the apparel industry are still new. Therefore, the standardization of related terms was primarily required. Experts in the ISO/TC 133/WG 2 proceeded to define terms related to digital fitting technology in the first standard proposal, ISO 18825-1, and the standard proposal of virtual garment, ISO 18163. Basic terms in digital fitting technology are as follows. Digital fitting technology is operated by a "virtual garment system," and a virtual garment system is comprised of "virtual space," "VHB," "virtual garment," "virtual garment simulation," and "digital fitting." "Virtual space" is a three dimensional digital space in which virtual garment is placed on VHB for the purpose of digital fitting. VHB refers to a three dimensional body model in the digital format existing in virtual space for digital fitting in the apparel industry (ISO 18825-1 2016b). A "virtual garment" is a three dimensional, digital clothing item that exists in the virtual space for digital fitting. "Virtual garment simulation" is defined as creating and drape-simulating a virtual garment for VHB in the use of a virtual garment pattern, virtual sewing, and bounding volume. "Digital fitting" refers to the qualitative and/or quantitative evaluation of overall or specific simulation of garment fit through analyzing the garment balance, gap between body and garment, heat map, surface wrinkles, and other related characteristics (ISO 18163 2016a).

Types of VHB

Types of VHB were clarified in the ISO 18825-1 (2016b). They are referred to as VHB-creating methods that are classified into "virtual clone" and "virtual twin." "Virtual clone," also called "virtual shape," is a VHB made by forming three-dimensional surface data from a 3D body generated point cloud (ISO 20685 2010). This was accomplished by using surface modeling processes, including noise elimination, hole-filling, and mesh generation. In order to create a virtual clone, it is essential to scan a user's body with a three dimensional scanner. As the body shape of the user is directly reflected, the virtual clone is almost identical to the body size and shape of the user (Fig. 1). "Virtual twin," also called "virtual size," refers to a morphed VHB that is applied to body dimensions acquired either through manual or automatic measurements. It is a type of parametric human body as it can be altered according to certain parameters. It is not identical to the user but represents a close approximation that can be altered by entering parameters retrieved from a population database (Fig. 2).

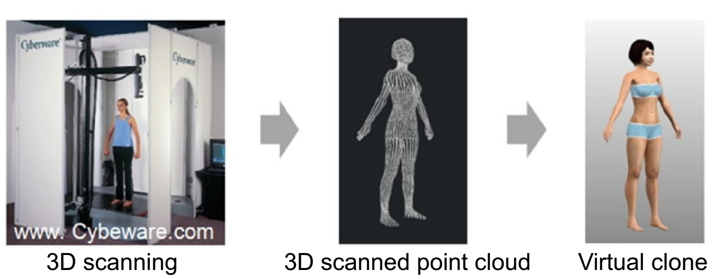

Fig. 1 Process of creating a virtual clone (ISO 18825-1 2016b)

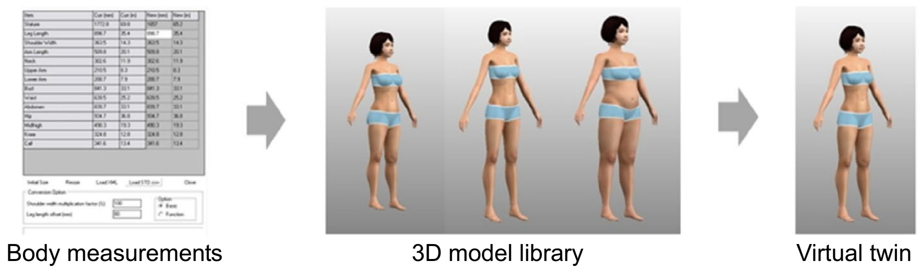

Fig. 2 Process of creating a virtual twin (ISO 18825-1 2016b)

Compositions of VHB

In the ISO 18825-1 (2016b), VHB compositions are regulated to be basic or optional. Basic compositions include virtual body segments, virtual cross-sections, virtual body dimensions, virtual landmarks, virtual skeletal structure, and virtual body textures. All VHBs are required to be equipped with basic compositions and must be able to express changes in attributes in the virtual garment system. Optional compositions include virtual body pose, virtual motion, and virtual flesh. Whether changes in these attributes are reflected is optional depending on the virtual garment system.

Size elements of VHB

Prior to defining the size elements of VHBs, it was required to regulate a fundamental VHB position. Measurements can differ depending on the direction of a palm (Lu et al. 2010) or a degree of arm or leg spreading (Kouchi and Mochimaru 2005). In the ISO 8559 (1989), the poses of a measured person were simply regulated in phases to be "measured with the arms hanging naturally" for "2.1.4 shoulder strength" and "with the subject standing upright" for "2.1.7 chest girth." In the ISO 20685 (2010), it was regulated in that "the position of the subject in the scanning volume was critical to obtain reliable data to be used in an anthropometric database." In addition, "4.1.3 standing" was regulated in the specific phrase indicating that "the head was in the Frankfurt plane, the feet were 20 cm apart, the arms were abducted to form a 20° angle with the sides of the torso, the forearms hung vertically, and the palms faced backward." In the ISO/IEC 19774 (2006) in the field of computer graphics, Humanoid Animation (H-Anim) was regulated as a pose with arms attached on the body. As VHB in the apparel field will be used to confirm virtual garment fit, maintaining a certain distance of the arms from the body was deemed to be effective. As such, "4.1.3 virtual standing position" was defined in the ISO 18825-1 (2016b) in reference to the angle of the head and arms and the location of feet in the ISO 20685 (2010), which suggests three dimensional body measuring poses. However, the direction of a palm facing backward was modified to face toward the torso as this was decided to be the natural direction of a palm (Fig. 3).

In the next stage, virtual body regions were established by the major base lines of size elements in ISO 18825-2 (2016c). The virtual torso of VHB is divided into virtual neck region, virtual shoulder region, virtual chest (bust) region, virtual waist region,

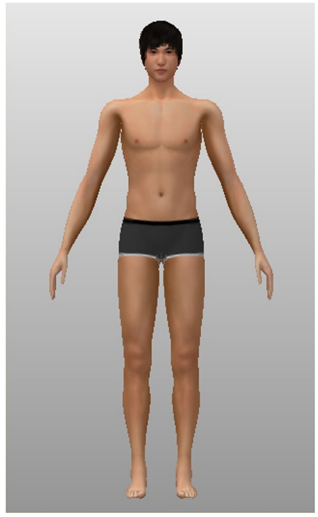

Fig. 3 Virtual standing position (ISO 18825-1 2016b)

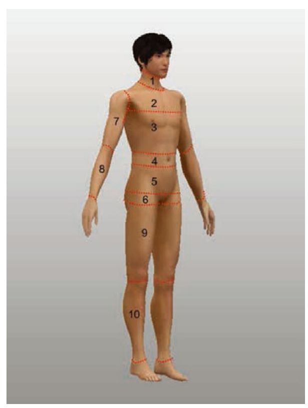

Fig. 4 Virtual body regions of the virtual torso, arms and legs (ISO 18825-2 2016c)

virtual abdomen region, and virtual crotch region, and the virtual arms of VHB consist of two virtual upper arm regions and two virtual forearm regions. Virtual legs of VHB consist of two virtual thigh regions and two virtual calf regions (Fig. 4). Such virtual body regions were developed considering the fundamental construction line in making garments for appropriateness of garment size and shape, and it is possible to alter the base line according to the virtual garment system.

In the next stage, terms and definitions of virtual landmarks and virtual body dimensions—the size elements of VHB—were regulated in ISO 18825-2 (2016c). In the standard, it was necessary to consider the characteristics of virtual space in which size elements must reflect actual bodies as much as possible. However, this process was completed without direct touch, convenience of user comprehension on the definition of size elements, convenience of utilization from users, efficiency of operation of the virtual garment system, and limit of current commercial technology. Therefore, an issue of choosing the degree of measuring routines of virtual landmarks and virtual body dimensions remained. According to the result of discussion in WG 2, the landmarks designated by finding points in the skeletal structure after directly touching human bodies were modified so that they could be searched only by using visually apparent elements after excluding the search based on anatomical skeletal structure. Body surface length items in connecting landmarks in the ISO 8559 (1989) were modified to the straight-line distance between three dimensional coordinates of virtual landmarks in the ISO 18825-2 (2016c). The difference between such a direct measuring method and the one applied to VHB is expected to supplement the standards in the future as digital fitting technology continues to advance.

Twenty-six essential virtual landmarks and twenty-eight virtual human dimensions defined in the ISO 18825-2 (2016c) are outlined in Table 2.

Size alteration of VHB

During the next stage, ISO 18825-2 (2016c) dealt with VHB size alteration. When users intend to create their VHBs for the first time, or if users who possess VHBs attempt to change them due to changes in body dimensions, it is possible to primarily utilize the virtual clone creating method. However, this method is only accessible if users can utilize a 3D scanner. Specialized manpower and programs that form three dimensional surface data from three dimensional point clouds are also required. Therefore, the virtual twin creating method acquired through changes in size by entering body measurements in the virtual garment system might be easier and more convenient. After selecting an exemplar model that is similar with users in the 3D model library, VHB size can be changed by entering body measurements as parameter values in the function of size alteration from the virtual garment system.

Issues in VHB size and shape reproducibility in the apparel field and standardization requirements

Current digital fitting technologies are transitioning into a phase of commercialization after new technology has been introduced. Therefore, it is necessary to guide accumulated technologies in the right direction for ultimate development in the apparel industry. Existing international standards only contain fundamental content related to the definition of terms, attributes of composition, expression, and alteration of VHB. Current international standards have briefly stated the size of VHB without contents about the shape. Therefore, additional standardization work is required to ensure reproducibility. In the Standardized Technology Development Project in South Korea, experts in the

Table 2 Essential virtual landmarks and virtual body dimensions (ISO 18825-2 2016c)

No.	Virtual landmark	Virtual body dimension
1	Virtual top head point	Virtual height
2	Virtual neck point	Virtual bust height
3	Virtual front neck-base point	Virtual waist height
4	Virtual side neck-base point	Virtual hip height
5	Virtual back neck-base point	Virtual crotch height (virtual inside leg length)
6	Virtual shoulder point	Virtual knee height
7	Virtual axilla point	Virtual calf height
8	Virtual front axilla point	Virtual shoulder width
9	Virtual back axilla point	Virtual back waist length
10	Virtual bust point	Virtual arm length
11	Virtual underbust point	Virtual neck girth
12	Virtual side waist point	Virtual neck-base girth
13	Virtual back waist point	Virtual armscye girth
14	Virtual abdomen point	Virtual upper arm girth
15	Virtual hip point	Virtual elbow girth
16	Virtual crotch point	Virtual wrist girth
17	Virtual elbow point	Virtual chest girth
18	Virtual wrist point	Virtual bust girth
19	Virtual middle finger tip point	Virtual underbust girth
20	Virtual gluteal fold point	Virtual waist girth
21	Virtual mid-thigh point	Virtual abdomen girth
22	Virtual knee point	Virtual hip girth
23	Virtual calf point	Virtual thigh girth
24	Virtual lower leg point	Virtual mid-thigh girth
25	Virtual outside ankle point	Virtual knee girth
26	Virtual landing heel point	Virtual calf girth
27	–	Virtual lower leg girth
28	–	Virtual ankle girth

fields of clothing, textiles, engineering, and standardization have suggested international standards in the ISO/TC 133/WG 2 from 2010 to 2016 while deriving current issues confronted by digital fitting technologies and seeking solutions. In this study, issues of VHB size and shape reproducibility that have been discussed by experts are outlined by conducting focus group interviews. In addition, industrial or academic requirements in the perspective of standardization have been organized as follows.

Issues of reproducibility in size and shape of VHB

In a study conducted on VHB size, Lee (2010) indicated that a slight error between scan data and real body measurements occurred while reducing the amount of data and correcting part of a hole when scanning. Many studies pointed out that terms and definitions of virtual body dimensions were not unified in each virtual garment system (Kang 2010; Kim et al. 2011; Choi et al. 2014). Difference in parameter definitions has caused led to a situation in which differently sized figures were created after entering the same sizes (Choi et al. 2014). Kim et al. (2011) suggested a level of virtual landmarks and virtual body dimensions that may be used in the apparel industry. This was accomplished by emphasizing the importance of unification in terms and definitions of virtual body dimensions and virtual landmarks for the reproducibility of VHB. Terms and definitions are typical subjects of standardization. Standards regulating terms and definitions of virtual landmarks and virtual body dimensions require stage-specific version depending on the purpose as well as fundamental versions. Lee and Sohn (2012) also indicated that virtual body dimensions could be different from real body measurements depending on body shape type among VHB data obtained by the size-entering method.

In a study on issues in the VHB shape, Lee and Sohn (2012) pointed out the distortion of body shapes and muscles and indicated that it was required to develop a prototype for changing the size of VHB based on actual body shape types for the commercialization of digital fitting technology as well as research in various types of body shapes. Shin (2009) pointed out that changed virtual body regions were limited when changing VHB. Concurrently, changes in the shapes of cross-sections were not reflected as reasons for differences in VHB shapes and the shapes of actual human bodies. Lim (2012) mentioned the necessity for developing VHB, noting how it was similar with an actual body in terms of shape as well as size since consumers tended to prefer purchasing virtual garments worn by VHB acquired by the figure data-entering method to one acquired by the size-entering method. Comprehending various and complex real bodies is required for developers of virtual garment systems. This research reveals that the establishment of a scientific method for analyzing body shape type is required. Choi et al. (2014) stated that a VHB alteration algorithm was required to ensure body reproducibility while using as few parameters as possible. In addition, they insisted that VHB covering various age groups and nationalities needed to be manufactured. In the field of computer science, Paul and Wischniewski (2012) suggested an issue of variability of digital human bodies that was derived from the difference of body data set according to the purpose, attributes, algorithm of function, and development. The purpose of utilization and targeted wearers must be considered when developing virtual garment systems. Convenience and accuracy of VHB reproduction may vary depending on the purpose. Combinations of demographic criteria such as country, nationality, and age may lead to variation. Kang (2010) pointed out that the issue of a broken figure of parametric human body occurred due to the collision between objects when entering body size far beyond the exemplar model. At the same time, the exemplar models indicated above must be developed in different sizes were reflect different age and clothing size groups.

Hereupon, issues of VHB suggested from the previous studies were mostly related to the reproducibility of bodies in terms of size and shape from the difference between VHB and actual bodies (Table 3). However, issues from those existing studies were considered to be insufficient because each study focused on fragmentary issues.

VHB standardization requirements

As the results of the focus group interview, industrial and academic requirements for the steps of VHB development were deduced.

Table 3 Requirements for VHB size and shape standardization derived from the existing research

Research	Derived requirements
Lee (2010)	Guideline for 3D data preparation
Kang (2010), Kim et al. (2011), Choi et al. (2014)	Unification of terms and definitions of virtual landmarks and virtual body dimensions Specific versions with stages depending on the purpose
Lee and Sohn (2012), Shin (2009), Lim (2012)	Comprehension related to various and complex actual bodies Establishment of scientific method for analysis of the body shape types
Choi et al. (2014), Paul and Wischniewski (2012)	Convenience of usability and accuracy of reproduction of VHB depending on the purpose Combination of demographic criteria depending on targeted wearers
Kang (2010)	Development of suitable exemplar model for segmentation of targeted wearers

Collection of body data according to the purpose and targeted wearers

Most users tend to change the size of exemplar model given in the virtual garment without knowing the principles of how the foundation is meant to be created or which data set is a basis. Different data sets tend to cause different relationship between body dimensions. Virtual twins are developed using the size altering algorithm to which such a relationship as above can have different shapes from bodies of people who wear them as pursued by users even if the size was similar (Lee and Sohn 2012). In order to solve such issues, it is necessary to establish the purpose and targeted wearers and collect the appropriate body data in the VHB development step.

Manufacturers and retailers are able to achieve efficiency and profit by utilizing VHBs based on body data if they are consistent with the concepts pursued by the company and targeted consumers. In addition, researchers can derive meaningful results according to special purposes for the study. Therefore, VHBs developed using body data according to the purpose and targeted wearers can enhance practical industrial and academic utility.

The level of entered parameters and body reproducibility tends to be different depending on the purpose. Some of the manufacturers or retailers that place high priority on convenience for consumers might prefer simple versions with convenient operation in spite of low body reproducibility. At the same time, some researchers might pursue a level of accurate body reproducibility by adding body dimensions depending on the study purpose. When designating targeted wearers, various demographic criteria including country, nationality, age, career, and life style may be combined and used. Criteria must be unambiguous, and the number of criteria shall be efficient for usage.

When collecting the body data of targeted wearers, body reproducibility shall not be limited to investigating or measuring data items. For this, it is required to preparatorily choose candidates of body categorization parameters as well as detailed body dimensions related to those parameters through the review of previous research and collect the body data of targeted wearers.

Three dimensional scanned data tend to exhibit different levels of reliability depending on the accuracy of scanning devices (Lu and Wang 2008) and fluency in editing work (Lee 2010). Therefore, developers must go through procedures to confirm whether measuring methods of scanned data and editing methods ensure reliability. In order to support them, it is required to establish regulations regarding reliability in collecting anthropometric data for VHB development on VHB-related standards.

Body measurements are the most fundamental elements in standardizing VHB size and shape. In previous studies, it has been mentioned that terms and definitions of virtual landmarks as a basis for virtual body dimensions shall be unified (Kim et al. 2011). In the ISO 18825-2 (2016c), basic terms and definitions were regulated. However, continuous efforts to unify terms and solve issues that are caused by not using identical definitions in virtual garment systems are required (Kang 2010; Choi et al. 2014).

Selection of criteria for body categorization and establishment of categorized exemplar model library

Exemplar model refers to a model with a default VHB size that can be chosen and loaded in the library as a space where 3D models are listed in the initial screen of the virtual garment system. This section is intended to discuss the selection of criteria for body categorization and the establishment of a categorized exemplar model library.

In many previous studies in the apparel industry, categorizing body size and shape has been suggested. However, most existing virtual garment systems applied to exemplar models with idealistic bodies were subjectively set without grounds in body type analysis. Cases were found in which adult women, adult men, female children, and male children were suggested as pure model spins or in which exemplar models roughly classified as fat, normal, and slim body types were suggested without an objective criteria of fatness. If such VHBs are used in online shopping, there may be a low possibility that purchased and shipped clothes fit the actual bodies of consumers. Since the results of digital fitting evaluation and real garment fitting evaluation are different, virtual garment systems may result in lowering the satisfaction of purchasing apparel products.

In order for digital fitting technology to be a solution to the disadvantages of existing online shopping, a degree of completeness of virtual garment systems must to be continuously enhanced until the results of digital fitting evaluation and real garment fitting evaluation reflect each other. The starting point is to ensure body reproducibility in VHBs through body categorization. If there is an attempt to change sizes from the exemplar model manufactured without grounds in body shape analysis in the development phase, virtual twins of wearers tend to be forced to fit the parameters. At the same time, detailed body dimensions change differently from actual bodies. In addition, shape reproducibility tends to degrade as characteristics of body shape are not reflected (Lee and Sohn 2012). As size is increasingly changed, the reproducibility of shape is increasingly degraded (Kang 2010). Therefore, it is necessary to categorize the body sizes and shapes of targeted wearers, as they are diversely distributed, and establish the exemplar model library for virtual garment systems. This is how users are able to load exemplar models that are categorically similar to themselves. The key point for the establishment of exemplar model library is whether it is possible for the final outcomes to be almost identical with wearers' actual bodies in both size and shape aspects after changing virtual twin size.

Creating virtual clones derived from the shape of an individual wearer with three dimensional scanning is one method of ensuring body reproducibility. However, establishing the categorized exemplar model library is required when producing not only virtual twins but also virtual clones. Wearers' body sizes tend to naturally and frequently change due to eating habits, aging, and exercise. Therefore, VHBs created using virtual clones must be able to effectively change in size.

The work for establishing the categorized exemplar model library begins from classifying body shape types by performing statistical analysis, such as factor analysis, cluster analysis (Song and Ashdown 2011), regression analysis, discriminant analysis, and logistic regression analysis, on collected body data of targeted wearers. In the course of classifying body shape types, distinctive body shape types are derived. Body categorization parameters that express body reproducibility and related detailed dimensions are selected. Body categorization parameters include angle, fatness, and flatness calculated by the cross-section and indices such as WHR that contributes to shape reproducibility as well as body measurements. VHB developers and researchers shall identify specific statistical relevance on major parameters that are highly influential in VHB size-altering algorithms and detailed body dimensions as they are influenced by major parameters (Shin 2009; Korean Agency for Technology and Standards 2013). This is to select body categorization parameters and detailed body dimensions. At this time, it is necessary to review whether body categorization parameters are clearly defined or whether the number of items plays a role in simplifying the procedure of searching for an exemplar model to be similar with a wearer. It is necessary to review whether the number of detailed body dimensions is relevant to the level of body reproduction and complexity in size-altering algorithms or whether it slows down size alteration. It is also necessary to confirm how much of the targeted population is covered by body shape types classified by chosen body categorization parameters.

In addition, the discriminants must be constituted as a tool for searching for the exemplar model to be approximate to an individual wearers' body by entering individual wearers' anthropometric and demographic information when using virtual garment systems. To constitute discriminants, discriminant analysis and logistic regression analysis may be used. Discriminant analysis makes it feasible to derive a combination of categorization criteria to produce a result that effectively discriminates body shape types. Logistic regression analysis has an advantage of confirming how appropriate the individual wearer is to each body shape type with numbers instead of finding a combination of categorization criteria. Therefore, it is recommended to use these two statistical methods to establish the combination of categorization criteria by discriminant analysis to derive discriminants and confirming the relevant rate in each body shape type of an individual wearer in logistic regression analysis.

Modeling of exemplar model figures and application of the size-altering algorithm

Once the type of exemplar model is determined, it is remodeled to only display the surfaces of a figure in which three-dimensional coordinate searching is available. There are several three dimensional figure modeling methods with which one may find a sample of an individual body figure that relates to representative measurements in each body shape type from three dimensional body database or create a combined body figure by morphing.

When representative body figures in each body shape type are obtained, the figure is cut along the cross-section that goes through major parameters and fits the curved lines and surfaces of the exemplar model figure. Fitting in curved lines and surfaces exclude errors from the curves of body figure to establish a smooth curve and build well-ordered curved surfaces (Kim and Park 2004).

Mathematical and geometric interaction formulae that are relevant to the size-altering algorithm are applied on the curved lines and surfaces of exemplar model figure (Li and Chen 2009). In the size-altering algorithm, landmarks obtained from landmarks as a base of the cross-section and body dimensions are relevant to independent variables that change the size of parametric surfaces. At this time, body dimensions searched from landmarks are identical with major parameters chosen in the previous "Selection of Criteria for Body Categorization and Establishment of Categorized Exemplar Model Library" section, which explains the selection of criteria for body categorization. Mathematical and geometric interaction formulae using three dimensional curves and coordinates as variables have been established. Additionally, academic and industrial efforts are required to find meaningful algorithms that ensure body reproducibility by comprehensively comparing various currently existing algorithms.

After constituting mathematical and geometric size-altering algorithms, the surfaces of exemplar model figures are converted to parametric surfaces by applying a size-altering algorithm (Kim and Park 2004).

Once the exemplar model is established in each body shape type and the size altering algorithm is completed, it is necessary to verify procedures for changing sizes by applying them to distinct cases. Two main verification procedures are required to secure VHB reproducibility and confirm whether the clothing fit on VHBs is appropriate. If inappropriate body regions or body dimensions are found, it is essential to review previous procedures and modify exemplar models.

Creation of customized VHB on an individual wearer

When a user accesses the virtual garment system and enters criteria information for body categorization, including their major parameter values, the virtual garment system searches similar exemplar models from the perspective of individual body shape type (ISO 18825-2 2016c). A user then modifies the customized VHB by changing the size of body figure according to entered information.

Usage of VHB does not simply occur once but includes multiple VHB changes according to actual changes in a human body over time. Terms and definitions of criteria information for body categorization must be standardized to the level at which users can understand. Users must be able to confirm the definitions of parameters and landmarks suggested in virtual garment systems.

Individual virtual twins are generated on a real-time basis. Therefore, it is possible to omit screen output of the initial exemplar model according to the virtual garment system. However, the search function for the exemplar model that is similar to the wearer must be included in the system regardless of whether it is shown. In the current virtual garment system, users need to find and load specific exemplar model files from their own computers. Therefore, it is recommended that systems are equipped with systematic and automatic search functions for users' convenience.

This issue may be alleviated with a save function for individual customized VHB, which allows the re-use of VHBs for online shopping or research. Therefore, there might be an issue of whether it is possible to export or import between virtual garment systems, between online shopping websites, and between virtual garment system and online shopping websites due to the file format. Due to the current issue in which various file formats are not compatible with each other (Kang 2010), it is necessary to investigate the current use of file formats and choose standardized file formats to secure compatibility among systems. As a basis for attributes, results and data in body categorization information, terms and definitions of body categorization criteria, assumptions in body measurements, used structural elements, and the relevance of structural elements, targeted groups must be available for input/output in other virtual garment systems (Paul and Wischniewski 2012).

Confirmation of effects of virtual garment systems

By performing digital fitting simulations and using them for online shopping or research, users are able to confirm whether VHBs are effectively reproducible. At this time, it is notable that it is possible to confirm whether VHB is well-made when verifying the effect of the virtual garment systems by placing virtual garments on VHB and comparing them to actual garments through digital fitting evaluation. Therefore, it is necessary to ensure reproducibility for how other composition in the virtual garment system—such as pose, motion, garment pattern, sewing conditions, material, and color—correspond with actual targets.

In order for digital fitting technology to be further developed, it is important that users recognize the effects of the virtual garment system and disseminate them. Therefore, developers, manufacturers, and marketers must develop a plan to confirm the effects of virtual garment systems, enhance consumers' satisfaction, and disseminate the digital fitting technology.

Summary of requirements for standardization of VHB

Finally, industrial and academic requirements from the perspective of standardization of VHB size and shape that were suggested in this study are summarized in Table 4.

Conclusions

First, this study organized the proceedings and major content of the ISO standards that were developed in an attempt to standardize existing digital fitting technology. Second, it suggested issues in VHB size and shape reproducibility in the apparel industry as an urgent problem. This study intends to emphasize the current situation in which terms and definitions of size elements have been standardized to ensure VHB reproducibility based on anthropometric data and body categorization for VHB development. Moreover, the categorized exemplar model library is regarded as a realistic and effective method that satisfies the needs of individual wearers of various body sizes and shapes.

Previous studies have explored the issues related to virtual garment systems. However, there has been not yet been an active attempt to solve these issues. This study is meaningful in that it sorted out major issues in virtual garment systems.

This study is valuable in that it explains which efforts have currently been made along with proceedings about VHB and additional issues that developers, manufacturers, distributors, marketers, and researchers currently face. Suggested industrial or academic requirements are anticipated to be helpful not only for standardization work but also for development and usage of VHB.

Table 4 Summary of VHB size and shape standardization requirements

Step	Requirements
1. Collection of body data according to the purpose of utilization and targeted wearers	Consideration of convenience and reproduction accuracy according to the purpose of utilization
	Unambiguous criteria of targeted wearers and efficient number of criteria for usage
	Preparatory selection of candidates of body categorization parameters and detailed body dimensions by reviewing previous research prior to collecting the body data of targeted wearers
	Confirmation of the reliability of scan data measuring and editing methods
	Unification of terms and definitions of virtual landmarks and virtual body dimensions
2. Selection of criteria for body categorization and establishment of categorized exemplar model library	Guarantee of body reproducibility through body categorization
	Classification of body shape types and selection of criteria for body categorization
	Development of body shape type judgement method on an individual wearer
3. Modeling of an exemplar model figure and application of size altering algorithm	Surface modeling of exemplar model figure
	Circular fitting and curved surface fitting of exemplar model figure
	Constitution of mathematical and geometric size altering algorithm
	Conversion to parametric surfaces applied with size altering algorithm
	Verification of size altering algorithm in an individual case
4. Creation of customized VHB on an individual wearer	Unification of terms and definitions of criteria information for body categorization
	Automatic searching function of exemplar model
	Standardization of file formats compatibility
5. Confirmation of effects of virtual garment systems	Confirmation of reproducibility of digital fitting simulation performance
	Development of confirmation method of effect and dissemination method of distribution of virtual garment systems

Digital fitting technology is currently facing a transition toward commercialization, but it exhibits many advantages and future potential. It is a solution to the issue of garment fit in online shopping (ISO 18825-1 2016b), reducing perceived risk to consumers (Suh and Oh 2006) and providing shopping value and satisfaction (You and Lee 2010). Digital fitting technology is expected to reduce time, effort, and expenses in planning or manufacturing products (Park and Choi 2013), while making it feasible for consumers to participate in manufacturing. This is because it is possible to deliver designs preferred by consumers (Lee 2010). Owing to the aforementioned advantages, digital fitting technology is anticipated to create a new market for customized production (Park and Kim 2008). If digital fitting technology is commercialized, and customized production is sustained, it is expected to bring about changes in the entire course of apparel production in ordering, production, distribution, and usage. Therefore, academic and industry experts must make an effort to guide this development in the right direction.

Additionally, standardizing digital fitting technology is still an issue, including body texture, body pose, motion, color, and material of virtual garment. Therefore, it is necessary to attempt to standardize them. As the next step of standardization of VHB size and shape, it is urgent to standardize VHB pose and motion. Research has recently been conducted to measure the changes in clothing compression from motion and utilized them as evaluation indices in garment fit and appropriateness of motion due to newly added functions that can create motion after changing VHB joint angles and measure virtual clothing compression in virtual garment systems (Liu et al. 2016, 2017). However, these VHBs do not reflect changes in actual body surfaces from motion, and virtual clothing compression uses the same unit as actual clothing compression without reflecting skin elasticity, material property, and principles of compression. They have caused confusion, which underscores the urgency of standardization. For standardization work on virtual pose and virtual motion, elements that are not evaluated in the garment fit in static pose might be considered by dealing with body pose and motion. Therefore, this approach will contribute the improvement of garment fit and enhance usability in the fields of sportswear, protective clothing, and functional clothing as well as everyday wear.

Standardization is not to simply unifying targets in the field but sharing and applying recommended standards to enhance efficiency, convenience, and reliability when targets serve their roles, further promoting positive development in the field. Based on academic and industrial requirements suggested in this study, it is anticipated that virtual garment systems will be positively and effectively developed and that the results contribute to general development in the apparel field.

Abbreviations

VHB: virtual human body; ISO: International Organization for Standardization; TC: Technical Committee; NWIP: New Work Item Proposal; WD: Working Draft; CD: Committee Draft; DIS: Draft International Standard; FDIS: Final Draft International Standard; WG: working group; WHR: waist hip ratio.

Authors' contributions

HSK deducted the issues in VHB size and shape reproducibility from the results of interviews and aggregated VHB Standardization Requirements. HEC carried out focus group interviews and deducted the issues in VHB size and shape reproducibility from the results of interviews. CKP proceeded the major content of International VHB Standards and reviewed preceding research. YJN proceeded the major content of International VHB Standard. All authors read and approved the final manuscript.

Acknowledgements

This work was supported by the National Research Foundation of Korea (NRF) Grant funded by the Korean Government(MSIT) (No.NRF-2016R1A5A1938472).

Competing interests

The authors declare that they have no competing interests.

Availability of data and materials

Not applicable.

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Received: 24 December 2018 Accepted: 7 May 2019
Published online: 17 November 2019

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