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Computational Design of Functional Clothing for Disabled People

Računalniško načrtovanje funkcionalne obleke za invalide

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Abstract

The purpose of clothing is to express an individual's style, and to meet the wearer's protection, functionality and comfort needs. Each of these requirements must be met in order to satisfy human needs and achieve a garment's functionality. Another function of clothing is to hide physical disabilities, if possible. The sitting position is very common in daily life. All clothing should therefore be comfortable in this position, as well. This is particularly important for disabled people who are restricted to the sitting position for their entire life due to their disabilities. These are people who suffer from paraplegia, multiple sclerosis or some injuries, and who have limited mobility using wheelchairs. This paper presents research on improving clothing design, adjusted to the special needs and demands of an individual, through the application of new technologies. In that respect, taking measurements is very important, as is the virtual simulation of garment fitting as the result of cuts adapted to the sitting position.
Keywords: functional clothing, disabled people, 3D scanning, virtual garment simulation

Izvleček

Oblačila so namenjena izražanju človekovega osebnega stila, zaščiti pred zunanjimi vplivi, funkcionalnosti in zagotavljanju udobja. Vse naštete zahteve je treba izpolniti, če želimo zadovoljiti človekove potrebe in doseči uporabnost oblačil. Poleg omenjenih funkcij poskušamo z oblačili skriti tudi fizične okvare. Sedeči položaj je v vsakdanjem življenju zelo pogost, zato bi morala biti vsa oblačila v tem položaju enako udobna, kar je še zlasti pomembno za invalide, ki so vse življenje omejeni na sedeči položaj. To so osebe s paraplegijo, multiplo sklerozo ali drugimi poškodbami, ki imajo zaradi uporabe invalidskih vozičkov omejeno mobilnost. V članku so predstavljene raziskave o uporabi naprednih tehnologij in izboljšav pri oblikovanju oblačil s prilagoditvami posebnim potrebam in zahtevam posameznika. Pri tem je zelo pomembna faza jemanje mer, kot tudi virtualna simulacija oblačila s krojnimi deli, prilagojenimi sedečemu položaju.
Ključne besede: funkcionalna oblačila, invalidi, 3-D skeniranje, virtualna simulacija oblačil

1 Introduction

In addition to protection, functionality and comfort, clothing has an aesthetic function, the purpose of which is to express the wearer's personal style and hide physical disabilities. However, clothing cannot always hide the physical disabilities of people who suffer from more severe disabilities. In such cases, clothing must meet the needs of a disabled person, while achieving the pure aesthetics of garments, as design has a significant effect on the human social dimension [1, 2].
Disability is an umbrella term for the impairments, limited activities and participation restrictions of an individual while performing the activities of daily living. Wheelchair users (people suffering from

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paraplegia, multiple sclerosis, muscular dystrophy and other disorders of the locomotor system) are most affected [1].

The most frequently used disability classification, drawn up by the World Health Organisation (ICIDH), classifies disabilities as: behaviour disabilities, communication disabilities, personal care disabilities, locomotor disabilities, particular skill disabilities and situational disabilities. A disability (congenital or acquired) can be physical, cognitive, mental, sensory, emotional, developmental and even combinations of these [3–5].

The body characteristics of disabled people (shape, size and limb mobility) indicate the following [6, 7]:

- loss of balance due to spine injuries and changes in a body shape, which results in asymmetry and an irregular body shape;
- poor blood circulation, low body temperature, the physical inactivity of damaged body parts, impaired muscle functions and muscular atrophy; and
- the clear extension of the relevant muscle group of the upper extremities with wheelchair users.

2 Functional clothing requirements for disabled people

The functional requirements affecting garment design are the wearer's limited mobility and the need for a comfortable garment that does not cause additional health problems, such as skin irritation, blood flow obstruction, etc. [8, 9]. Clothing for disabled people must provide ergonomic comfort in the sitting position and improve the overall quality of life. It is designed for people from a physical and cognitive point of view, cultural and social aspects, and other aspects related to body dynamics [1, 10].

The problems faced by wheelchair users while dressing have been researched by Pruthi et al., and the following have been identified [11]:

- pain in the upper limbs while dressing and undressing;
- the removal of clothing from dormant legs;
- incontinence;
- bedsores caused by a lack of movement; and
- injuries caused by traction belts, etc. [12]

In order for the functionality of clothing for disabled people to be achieved, the following requirements must be met [1, 10, 13, 14]:

- moisture absorbency;
- the use of elastic fibres for comfort;
- the use of easy closure systems (zippers, hook-and-loop fasteners, buttons, etc.);
- easy to maintain clothing with a low level of electrostatic charging; and
- a minimum level of body odour retention (natural fibres with antibacterial finishing).

Clothing designed for disabled people must meet the following needs: sleeves should be adapted to the back and shoulders, facilitating more freedom of movement while pushing a wheelchair, comfort should be ensured, without fabric creases caused by sitting for long periods, trousers should not be too tight (blood flow obstruction due to strong pressure) or too loose (skin irritation on the back and hips due to fabric creases), and should be high-wasted on the back compared with standard clothing and should not tighten around the knees and create needless creases, and the pockets should not be sewed on the back of trousers and should be longer than standard cuts [13, 16]. Sleeves in the elbow area should also be shaped according to the principles of comfort, where it is possible to find constructional solutions, as shown in Figure 1.

Figure 1: Elbow part of an adaptive garment for wheelchair users [15]

Figure 2: Adaptive designs for sitting [20–22]

Research has shown that the comfort of trousers is affected by four main areas in which pressure occurs: waist (39.17%), knees (16.4%), crotch (13.96%) and the back of the thighs-calves (6.95%), while pressure on parts below the knees and the back of the thighs has no significant effect on wearing comfort. Wearing comfort is acceptable if pressure is below 20 kPa on the hips, waist and crotch, and below 10 kPa on the back of the thighs and knees [17, 18]. Research conducted in 2013 among 10 young women aged 18 to 38 with different types of disabilities suggested that design, form, function, self-expression and social identity were the essential factors that influence their clothing selection [19]. Standing posture measurements are not applicable to sitting posture measurements due to anatomical variations and different types of disabilities. For this reason, clothing designers and manufacturers should design this type of clothing according to the principles of universal design, i.e. inclusive design (Figure 2) [23–25].

3 3D virtual body scanning as a basis for designing personalised clothing for disabled people

Body measurement standards differ significantly between people with physical disabilities and non-disabled people. Thus, specific design requirements should be met when measuring disabled people [26–28].

When a person in the sitting position is being measured, it is important that seat surfaces be flat and horizontal, that the upper legs are positioned horizontally and the shins vertically, and that the feet

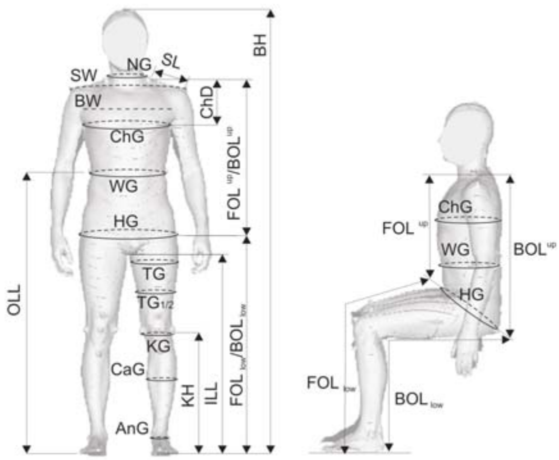

Figure 3: Definition of measurements on a 3D point cloud of the human body in the standing and sitting positions [29]

are positioned flat on a horizontal surface. The person must be barefoot and not wear any clothing except underwear [28, 30].

Body measurements can be taken manually or on a digitised human body. Depending on the applied measurement technique, differences in the volume of a body ranging from 0.72 cm to 1.71 cm and differences in body measurements in relation to the height and length of a body can arise [31, 32].

In order to take body measurements using a non-contact technique, digitisation with 3D body scanners is used, resulting in a point cloud of human body spatial coordinates. Scanning technologies can be classified into different categories: laser scanning, white light scanning, passive scanning, photogrammetry, visual body shape, silhouettes and the use of other active sensors [33–35].

The main advantage of a non-contact technique used for body measuring is the short scanning time required, which reduces the fatigue that occurs while maintaining specific and necessary postures during anthropometric measurements. It is possible to collect all relevant data from an anthropometric, biomechanical and ergonomic point of view, which is necessary for the development and design of clothing adapted to the different needs of specific segments of wearers. Given that anthropometry provides two body measurement systems static or structural referring to an individual's body variations, and dynamic or functional referring to biomechanical aspects related to different movements and daily tasks all of the afore-mentioned aspects can be comprised on the basis of 3D body scanning [10, 36].

Optoelectronic devices and scanners, which are based on recognising a silhouette from one or more images and can create a model with thousands of points using laser beams or structured light, are used to create a parametric model of the human body. However, a large number of points is redundant, noise is present and the surface for creating 3D models should be removed and filtered [37–39].

Figure 4: Intellifit radio scanner [39]

3D radio-wave scanners (Intellifit system) are based on radio-wave technology and use millimetre radio waves that pass through a subject's clothing and reflect off the body's surface. The reflected signal is subsequently detected by the receiver net, resulting in a 3D image of the subject (Figure 4) [37, 40–42].

The advancement of 3D scanning technology has enabled the creation of high-density point clouds. The process requires the use of certain algorithms that analyse the data of body topology in order to obtain the corresponding surface of the scanned object. At an early stage of data procession, discontinuities are discovered by the algorithms, so that the information can be kept during the complete process of surface interpolation.

The virtual prototyping of garments and simulation depend on numerous factors. The central focus of virtual image research is the development of the efficiency of mechanical and simulation models that can be reproduced. The second research aspect is aimed at 3D human body scanning and modelling in order to obtain a 3D human body model for the virtual prototyping of garments. Most research is based on the human body in the standing position with no or minor physical deformities. It is therefore aimed at the similar creation of virtual prototypes for wheelchair users [36, 40, 42–43].

Systems used for virtual garment fitting provide a standing parametric human body model of average height, with adapted shapes and dimensions. The aim of research is to design a generally acceptable 3D human body model adaptable to different poses and non-standard body shapes to enable the virtual prototyping of garments for people with limited body abilities; see Figure 5 [44–51].

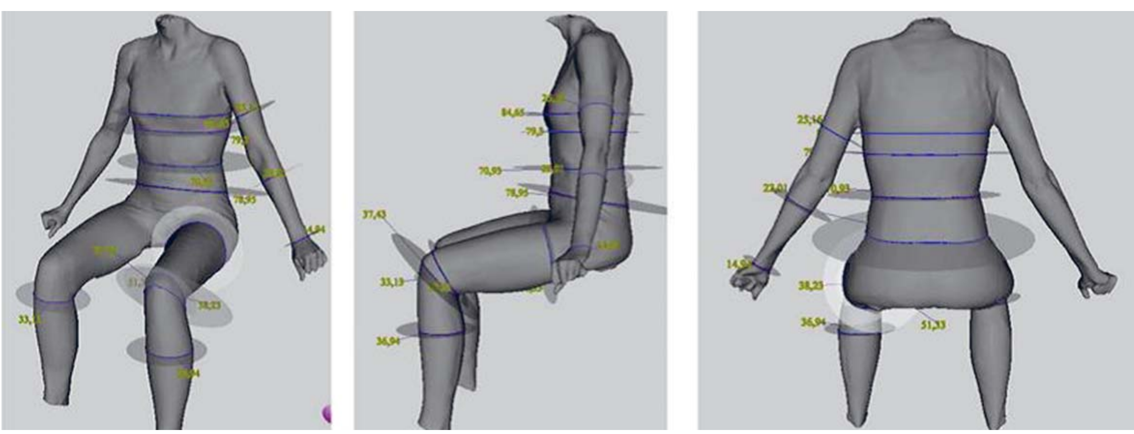

Figure 5: Parametric human body model in the sitting position [6]

The 3D point cloud has outliers in parallel with a lack of points on the digitised object. The point cloud is therefore reconstructed by removing outliers and closing the point cloud [39, 45]. The net must be completed by closing the point cloud in places where points are lacking. Taking into account the natural contours of the body, the points are added and the net is completed. The Poisson reconstruction algorithm is used for the surface reconstruction of a 3D body cloud.

Different methods for human body modelling have been developed. Their use has simplified the ways in which human body shapes and height are adapted. Linear regression is used for taking measurements [52–54].

4 Virtual garment design for people with disabilities

Adaptive clothing can be designed on the basis of a digitised human body. Characteristic body parts, such as the chest, shoulders, scapula, neck, back, hips and lateral parts, can be positioned depending on the actual body image, which is a prerequisite for virtual garment design. The research conducted and approaches applied have shown that the problem of adaptive design for people with disabilities, such as people with scoliosis, can be solved in this manner. The results of the research can thus be applied to mass production, facilitating rapid interaction between wearers and designers. In that regard, the parametric influence of textiles is crucial for adaptive clothing for wheelchair users [55–57].

An individual approach must be taken when designing garments for people with disabilities due to an individual's different physical deformities, which can be multiple with wheelchair users. For this purpose, a group of Slovenian researchers has developed the CASP method (C-curvature, A-acceleration, S-symmetry and P-proportionality) used to design clothing adapted to 3D virtual mannequins with physical deformities that have occurred as the result of disease. Curvature goes from minus (concavity) to plus (convexity), which can be calculated using the matrix expressions [58]:

$$\begin{bmatrix} a\,n-1,0 & \gg a\,n-1,n-1 \\ \vdots & \vdots \\ a\,0,0 & \gg a\,0,n-1 \end{bmatrix} \quad (1).$$

The matrix enables the same points in the 3D space in the n × n matrix to be marked. Acceleration is a property referring to the basic surfaces in a longitudinal direction. Clothing symmetry is always preferable, and a value of zero means perfect symmetry. Proportionality indicates the size or width of the surface, and is calculated as a ratio of the length and width of the observed surface. The whole process is based on the use of the Grasshopper® (GH) graphical algorithm, which is an add-in used with the RH application through which the analysis of digitised surface geometries is based on the rules of the M. Müller & Son and the Optitex CAD/PDS construction system. The latter enables the XY clothing tightness on particular body parts to be recorded in order to design comfortable adaptive clothing for people with disabilities [58, 59].

With the use of a 3D-to-2D garment design method, clothing can be designed directly on a 3D virtual body model, resulting in 2D patterns obtained by flattening the existing parts. Adaptive clothing is designed using a CAD system for designing the virtual prototyping of garments. This enables garment fit testing and the adjustment of virtual body models to standard models [2, 6, 45, 49, 59].

Making a virtual body model using the 3ds MAX software is based on integrating female body scan data with a kinematic template. The template position

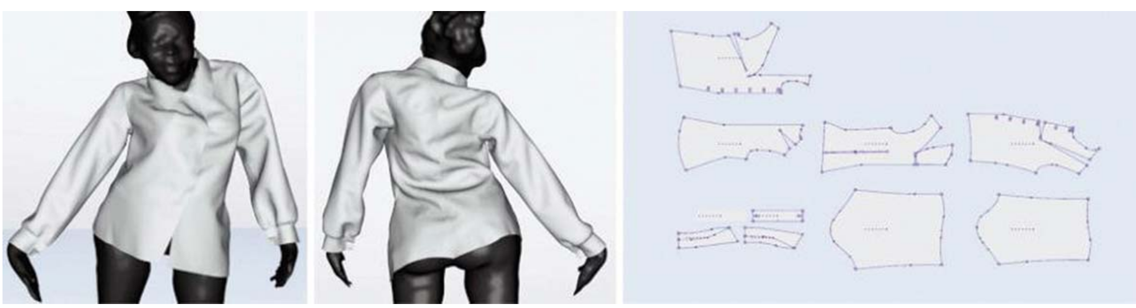

Figure 6: Adaptive clothing image created using a 3D-to-2D garment design method [49]

is adjusted to the scan data. The dimensions of bones and muscles are then adjusted to specific scan data.

In order for the animation to be realised, the interpolation weights must be transferred and calculated, enabling every joint to be marked and proportionally transferred between the skeleton and the network in order to obtain a uniform human body deformation. The process requires the use of different scripts developed for 3D kinematic model animation, the purpose of which is to create several lower body positions with different bending angles [60].

In research on the 3D construction and simulation of trousers designed using the Lectra DesignConcept, three distinctive positions with different degrees of bending at the knees and trunk have been described in detail. The contour of trousers has been defined and used for designing a mesh model from which 2D tailored pieces have been extracted. Research has shown that suitable tailored pieces cannot be extracted if a body has a high-degree bend. When the bend at the knees is 90º and 110º in the sitting position, it is automatically possible to design tailored pieces for well-fitting trousers. By changing the design and resizing the projected seam, a model that facilitates a bend of more than 130º at the knees and trunk is created, with no change in trouser fitting and the functionality of a garment for wheelchair users. The use of tailored pieces and the simulation generated positive

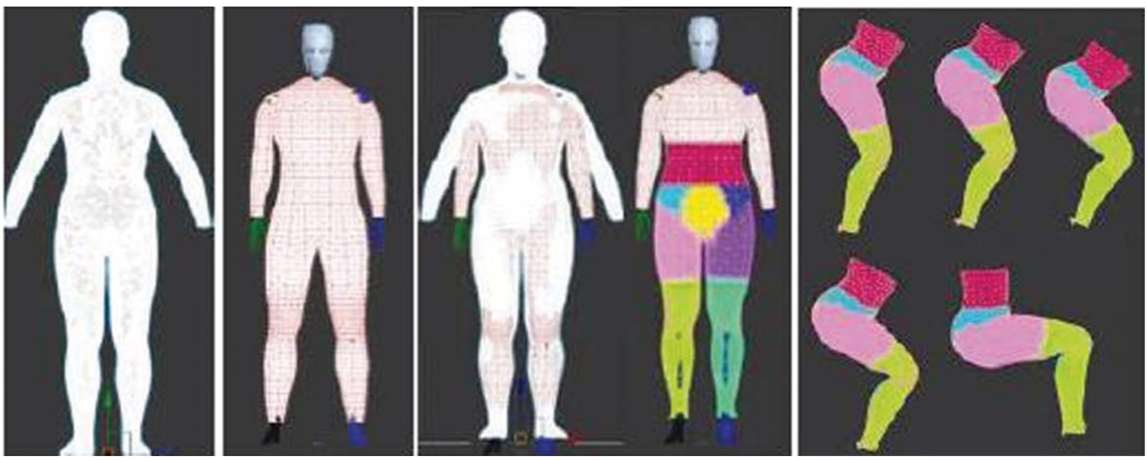

Figure 7: 3D human body animations in different positions [60]

Figure 8: Developing trouser patterns for people in the sitting position [65]

results, which is evident in prototyping. However, this method of design cannot be applied to all wheelchair users, as garment design depends on a person's individual needs and body morphology [61–63].

Research on improving the functionality of garments for wheelchair users has also been conducted. A robotic mannequin has been developed for the purpose of assessing clothing comfort based on the replication of body movements and data gathered through the senses while wearing clothing. A special application was developed for the purpose of this research. The application enables virtual garment fitting in the sitting position (wheelchair seating), provides a simulation of clothing adjustments according to changes to the standard model, performs 3D measurements on the basis of which a database is created, and verifies suitable results based on 3D visualisation. The purpose of the application was to provide a virtual service through adaptation, to enable wheelchair users to create a prototype wherever they wish and to gather data relating to apparel appearance [63–66].

5 Conclusion

After reviewing the relevant literature, it can be concluded that techniques for clothing simulation represent an important tool for textile and clothing designers. These techniques offer numerous advantages, such as fast and simple changes in clothing development. The primary advantage of virtual prototyping is the possibility of designing clothing and directly observing the adjustment of a silhouette to a person who is not physically present. Computer prototyping has great potential for producing clothing in a contemporary manner, as it facilitates a 3D prototype of a garment to be produced rapidly [67].

3D body scanning plays a key role in producing adaptive clothing for wheelchair users, as it allows body measurements to be taken while determining the posture and position of a body in the sitting position. Point clouds produced through the process of 3D scanning are used to create a virtual body, which is standard practice in the virtual prototyping of garments.

The standard software packages used for the virtual prototyping of garments can also be used for the virtual prototyping of garments for people with physical deformities. A systematic approach is necessary when designing clothing for people in wheelchairs. 3D scanning must be adapted to a person in the sitting position, particularly if the person is unable to sit without a seat back. When creating virtual bodies, an individual approach is required, as the point clouds of a body scan must be processed with the use of 3D image processing algorithms. The algorithms used for the standard standing position are not reliable enough for an automatic reconstruction of a 3D human body in the sitting position due to the differing body shapes of people with disabilities.

Software packages for apparel design are used to design a garment directly on a digitised 3D human body model. It is possible to either design and adjust a cut to a 3D body scan based on a simulation, or to create a garment directly on a 3D body by extracting the tailored pieces after 3D modelling.

Regardless of the selected method for garment design, obtaining satisfactory results is limited by a person's different body shape and physical limitations. It can thus be concluded that research on the computational design of clothing for people with disabilities has great potential. People with disabilities wish to emphasise their individuality, as aesthetically pleasing clothing decorates their physical appearance and enables them to enjoy a psychologically healthy environment [62].

Clothing for wheelchair users must be above all functional, must enable quick and independent dressing, must provide a psychical and psychological sense of comfort and stability, and be easy to maintain and trendy. The use of computer technologies is thus very important, as disadvantages to design can be foreseen and eliminated when developing and designing garments. The use of new technologies facilitates the design of functional garments for wheelchair users.

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