Development of Clothing-Related Assistance Systems to Support the Mobility

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Abstract

The aim of this research is the development of a clothing assistance system to support the mobility of older people, especially the movement from sitting to standing. The solution adapts to the body proportions, postures and movements that change with age without reducing the body's own strength and counteracting muscle degeneration. The energy storage and release required for support is realised by textile materials with different levels of strain stiffness. A wide range of elastic drawstrings is available for this purpose. Their integration into the overall system of the functional clothing in terms of production technology is intended to provide proportional support for muscle strength on the one hand and ensures good wearing comfort on the other. The result of the development is a passive exosuit in the form of functional underwear that can be worn under daywear.

Keywords: smart clothing, 3D/4D bodyscanning, human model

1. Introduction

Mobility is a basic human need and an essential prerequisite for social integration into society. With increasing life expectancy and the associated demographic change, the issue of mobility will become increasingly important in the future. Due to physical limitations, older people avoid leaving their homes without assistance. The loss of mobility is one of the major risks of ageing [1].

In recent years, wearable robots, suits or devices have been developed using robotics and mechatronics that help support human mobility by means of external forces (active exoskeletons) [2]. Current research is looking at the design of soft exosuits, which are also based on the action of external forces [3]. From a medical point of view, the use of such solutions for older people who have only age-related physical limitations is controversial. Missing active movement usually leads to a regression of the musculature. That would not be in the interest of potential users.

For many years, work has been done on material and cut development for functional clothing in the field of high-performance and leisure sports [4-8]. The needs of older people have not been the focus of interest. The aim of this research is therefore to support the mobility of older people through clothing assistance solutions without reducing the body's own strength and muscle degeneration.

The necessary process steps for product development for an assistance solution to support the stand-up movement (sit-to-stand/STS) are shown.

2. Methods to development textile passive exosuits

Clothing assistance systems for STS movement are being developed in the form of functional underwear that can be worn under normal daywear. These consist of textile materials of different levels of strain stiffness that enhance the movement of the person through targeted energy storage and release. The textile support is adjusted to the required muscle forces, whereby a compromise must be found between support level and wearing comfort. The load-adapted material selection is based on biomechanical modelling/simulation as well as the textile-physical material characterisation. Figure 1 explains the steps needed to be carried out to achieve the research study objective. In this paper, the focus is on virtual product development with 3D construction and simulation methods.

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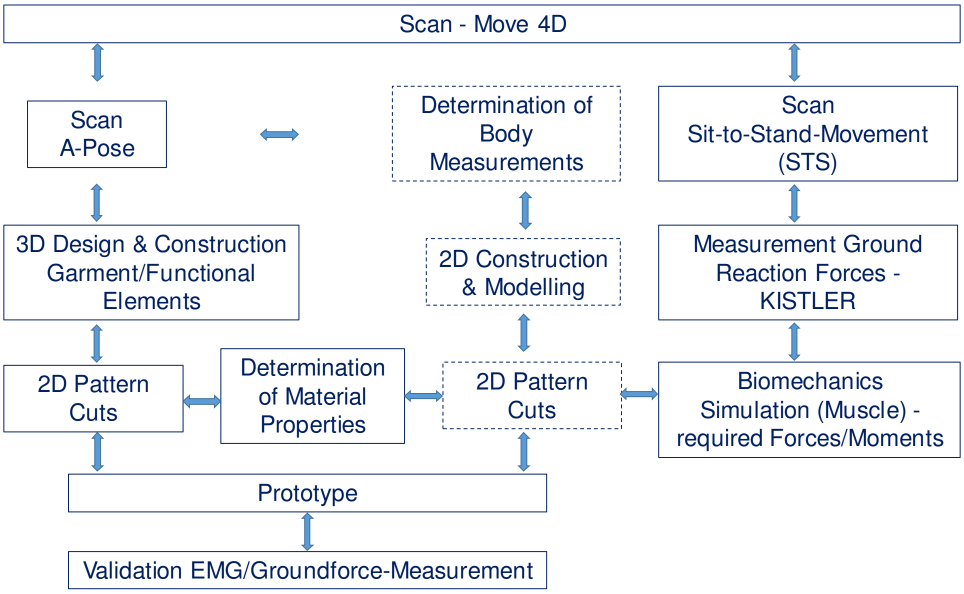


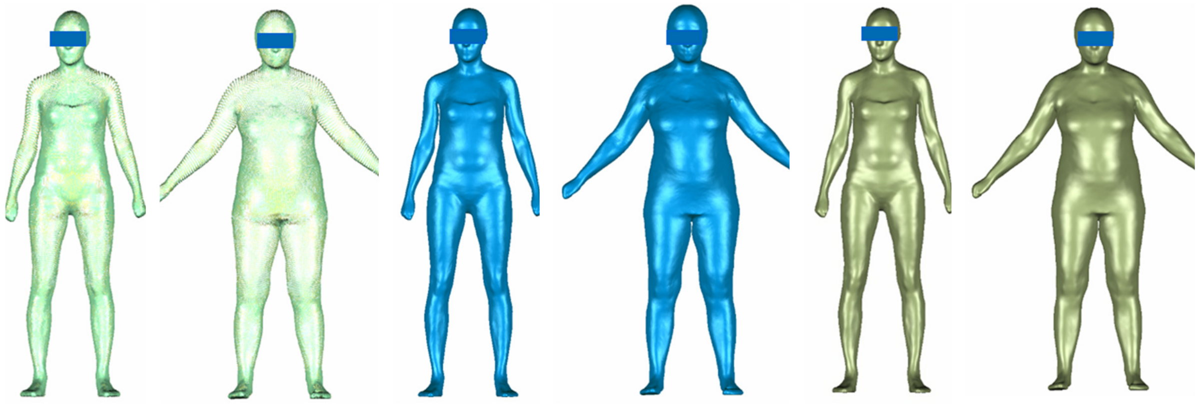
Fig. 1. Process chain for the development of passive exosuits.

2.1. Generation of scan data of mobility-impaired persons

3D/4D geometric data are required for the 3D construction of functional underwear as well as for the simulation of muscle forces using a muscle-joint model and for the animation of movements. For this purpose, both a healthy test person (1) with no movement restrictions and a test person (2) with movement restrictions (older than 65 years) are selected and scanned with the help of a 4D body scanner Move 4D [9]. The healthy subject is needed as a reference and allows the methodology described in Figure 1 to be worked out. The scanning is done with tight-fitting clothing in the standard scanning posture. This is a prerequisite for realistic imaging of the deformation of the body surface during movement as well as for determining the standard body dimensions for further use in alternative design solutions (2D design). The previously defined STS movement is then scanned to analyse the kinematics of the movement and to record the joint angles (see figure 2).

Fig. 2. Scanning of test person 2 in standard posture (left) and during STS movement (right).

After processing the captured data, the geometry data for the two test persons are available for the standard posture and for each individual time step of the STS movement. These are polygon models for further use in various simulation routines as well as CAD surfaces for further use in the 3D pattern design (see figure 3).



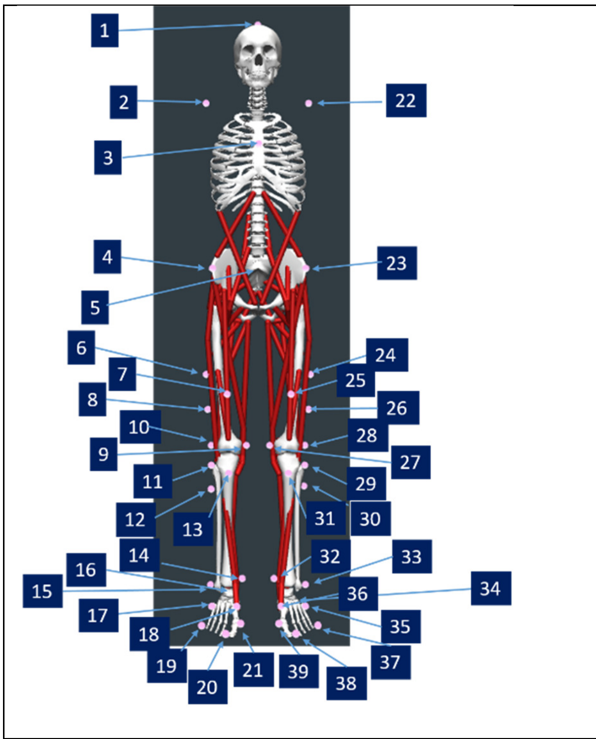
Point cloud Polygon model CAD-surfaces

Fig. 3. Processing the scan data.

2.2. Development of the individual biomechanical model to simulate the muscle forces

Biomechanical human models are required to simulate muscle forces. This needs a template model consisting of a skeleton and muscles. In this work, the standard model Gait 2392 from Opensim (see figure 4) is used and adapted to the individual scan data sets [10].

Therefore a scaling of the skeleton and the associated muscle groups is required. Using the virtual marker points defined in Opensim as well as the markers defined by Move 4D for implementing the skeleton in individual scan data, it was possible to determine the scaling factors for the respective marker pairs (for example, length of the torso: top head - v. sacral). The positioning of the markers on the human body partly varies in the different software solutions. This must be taken into account and adjusted manually. Finally, a template scaled according to individual body dimensions is available for further simulation.



2	R.Acromium	22	L.Acromium
4	R.ASIS	23	L.ASIS
6	R.Thigh.Upper	24	L.Thigh.Upper
7	R.Thigh.Front	25	L.Thigh.Front
8	R.Thigh.Rear	26	L.Thigh.Rear
9	R.Knee.Med	27	L.Knee.Med
10	R.Knee.Lat	28	L.Knee.Lat
11	R.Shank.Upper	29	L.Shank.Upper
12	R.Shank.Rear	30	L.Shank.Rear
13	R.Shank.Front	31	L.Shank.Front
14	R.Ankle.Med	32	L.Ankle.Med
15	R.Ankle.Lat	33	L.Ankle.Lat
16	R.Heel	34	L.Heel
17	R.Midfoot.Lat	35	L.Midfoot.Lat
18	R.Midfoot.Sup	36	L.Midfoot.Sup
19	R.Toe.Lat	37	L.Toe.Lat
20	R.Toe.Tip	38	L.Toe.Tip
21	R.Toe.Med	39	L.Toe.Med
1	Top.Head		
3	Sternum		
5	V.Sacral		

Fig. 4. Template model of Opensim with the defined marker points [10].

Furthermore, adjustments are necessary with regard to the coordinate system, which can be realised with the help of the Maya software [11]. This creates the prerequisite for loading the fbx transformation (motion data) from the Move 4D scan into Opensim. The definition of the individual time steps is done in a motion file.

With the help of this template model, the individual scan data are converted into a movable biomechanical model. The previously defined STS movement is considered by using kinematic chains (see figure 5).

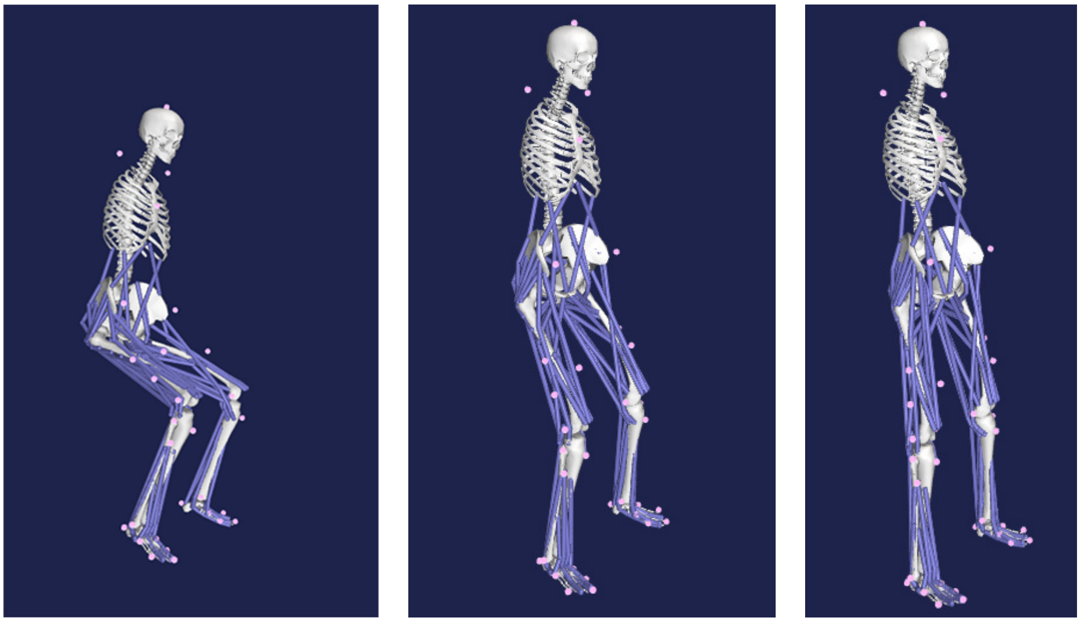


Fig. 5. Modelling the STS movement in Opensim (test person 2).

2.3. Calculation of muscle forces

Weight and inertial forces and the effect of the musculature determine the forces and moments resulting from the movement of the joints. In order to quantify the required muscle forces for a defined movement, the biomechanical human model created is used in the Opensim software. With the help of the integrated "Dynamics" software tool, forces and moments can be determined that cause a specific movement. Requirement is the experimental determination of the ground reaction, shear and forward forces as well as of the accelerations. These are established on the basis of the stored kinematics and the mass properties of the model. From this, the required muscle forces can be calculated.

2.3.1. Experimental recording of all forces during the movement

The experimental setup is designed in such a way that simultaneous recording of the scan data of the STS movement and the associated ground reaction forces are possible (see figure 6). For this purpose, the chair had to be modified so that as little shadowing as possible occurs during scanning (seat made of acrylic glass).

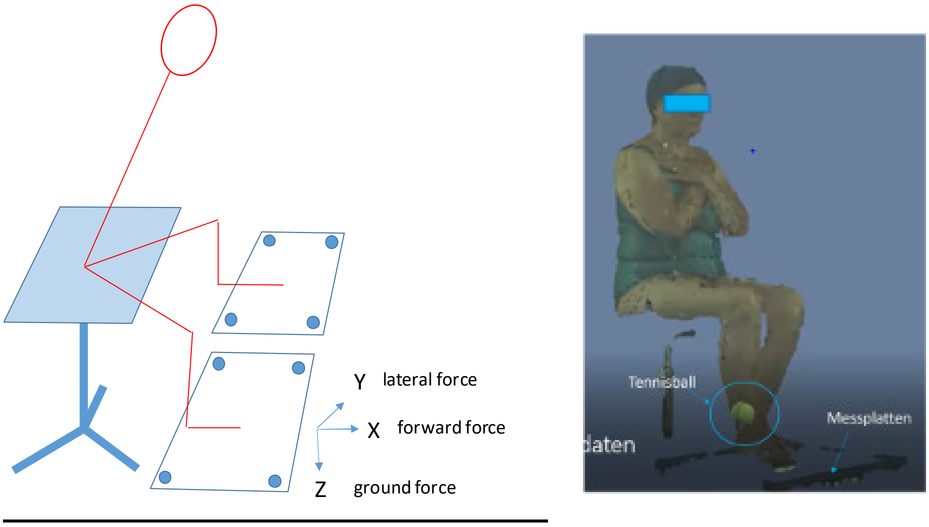


Fig. 6. Experimental setup.

A mobile 3D force measuring plate up to 5 kN (type 9260 AA3, 30 x 50 cm) from Kistler [12], a data acquisition system and the required software BioWare® for data analysis are used to record ground reaction, shear and forward forces for each foot. High-precision piezoelectric sensors enable the measurement of forces and moments, so that they can be used for biomechanical issues in science and rehabilitation as well as in sports. In addition, the Kistler force measurement allows the exact calculation of the point of force application (COP – Center Of Pressure) for precise inverse kinematics. For the recording of the STS movement, it is triggered with the scan recordings so that a simple assignment of the kinematics to the respective forces and moments is possible (see figure 6, right).
As a result of the measurements, time-dependent curves are obtained for both the force and the moment in all three directions (right foot - continuous line; left foot - dashed line), as shown in figure 7 for test person 2. The STS-movement consist of 4 phases, the torso forward swinging phase (1), the seat-off phase (2), the stretching phase (3) and the balancing phase (4).

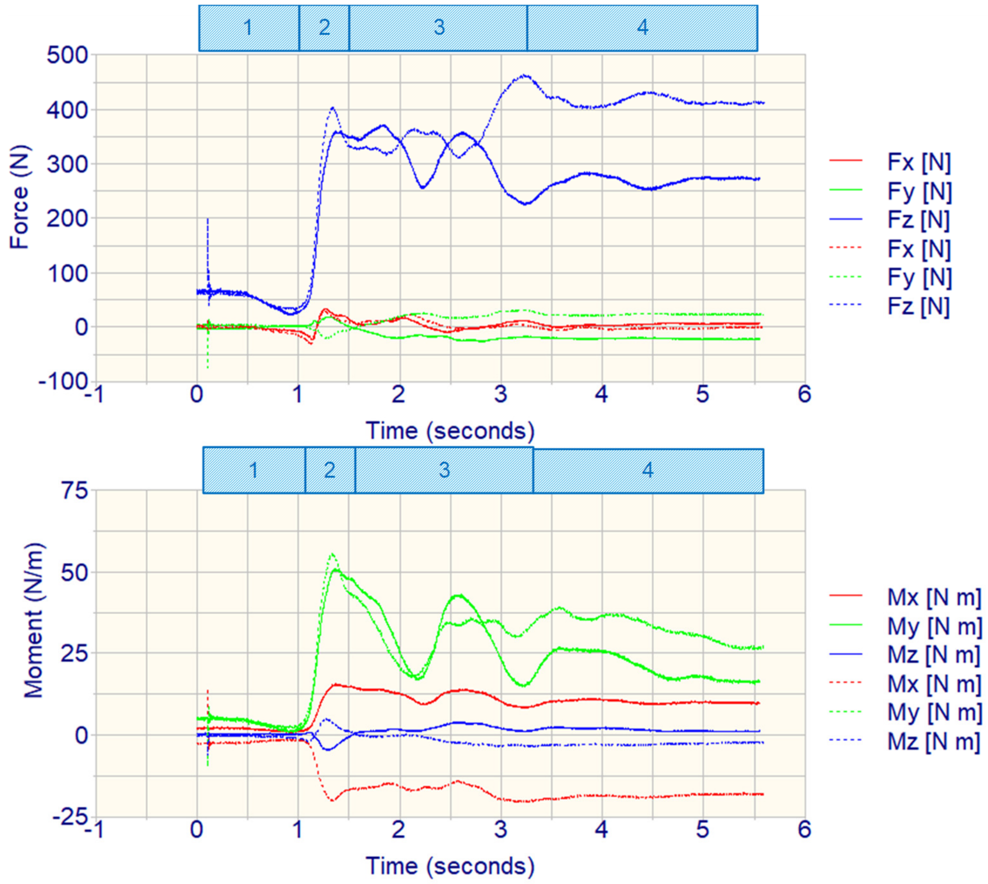
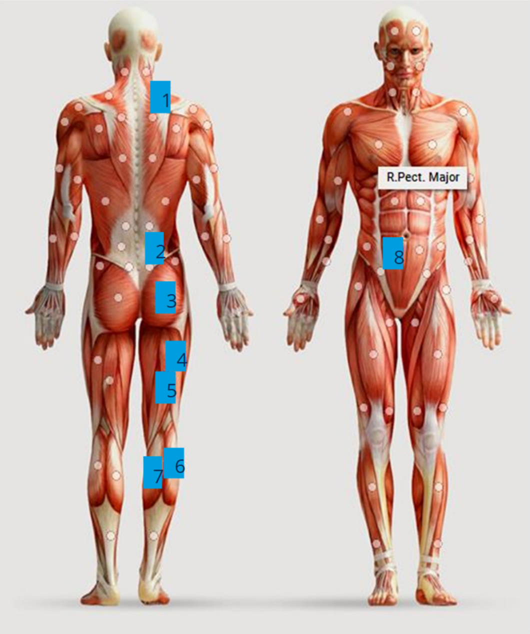


Fig. 7. Measurement results for test person 2, without assistance system, with parallel foot position.

2.3.2. Simulation the muscle forces in Opensim

For the biomechanical modelling, the muscle groups responsible for the defined movement are identified initially. The most important muscle groups are shown in figure 8.



Nr.	Muscle group
1	Upper Trapezius
2	Lumbar Erector Spinae
3	Gluteus Maximus
4	Biceps Femoris
5	Semitendinosus
6	Gastrocnemius lat.
7	Gastrocnemius med.
8	Rectus Abdominis

Fig. 8. Relevant muscle groups for realising the STS movement.

First, the joint angles and positions are determined using inverse kinematics. The basis for this are the fbx data imported into Opensim from the Move4D scan. Figure 9 shows the modelling of the STS movement with the simulated ground reaction forces and the changing centre of mass.

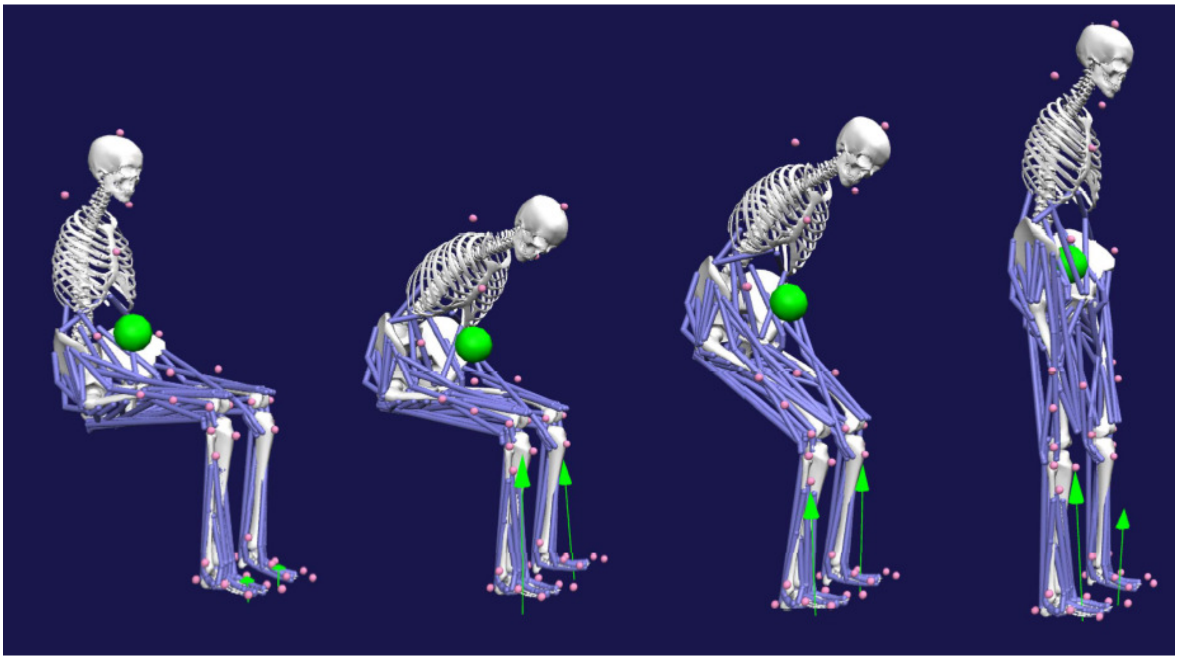
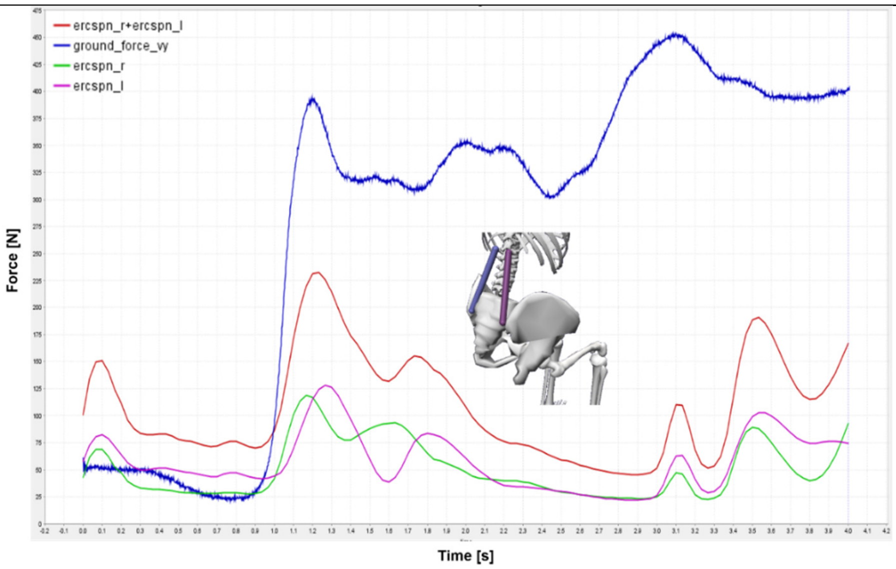


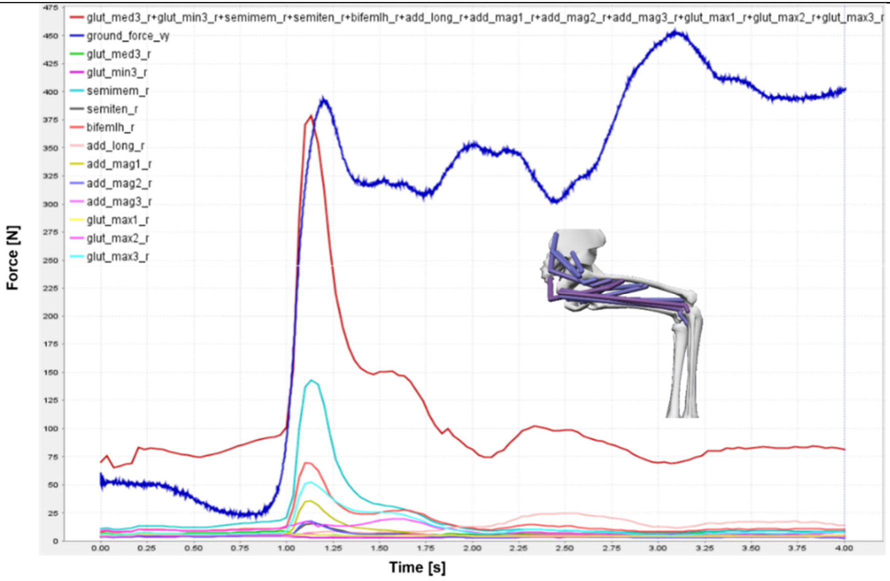
Fig. 9: Simulation of the STS motion, the vertical ground reaction forces as well as the centre of mass in OpenSim based on the fbx scan data (test person 2).

Subsequently, based on the previously determined ground reaction forces, the corresponding joint moments are calculated using static optimisation, an extension of inverse dynamics, and resolved into the individual muscle forces for each time step. These are calculated by minimising the sum of the quadratic muscle activations. The simulation of the muscle forces is carried out for the muscle groups required for the STS movement and is shown as an example in figure 10.

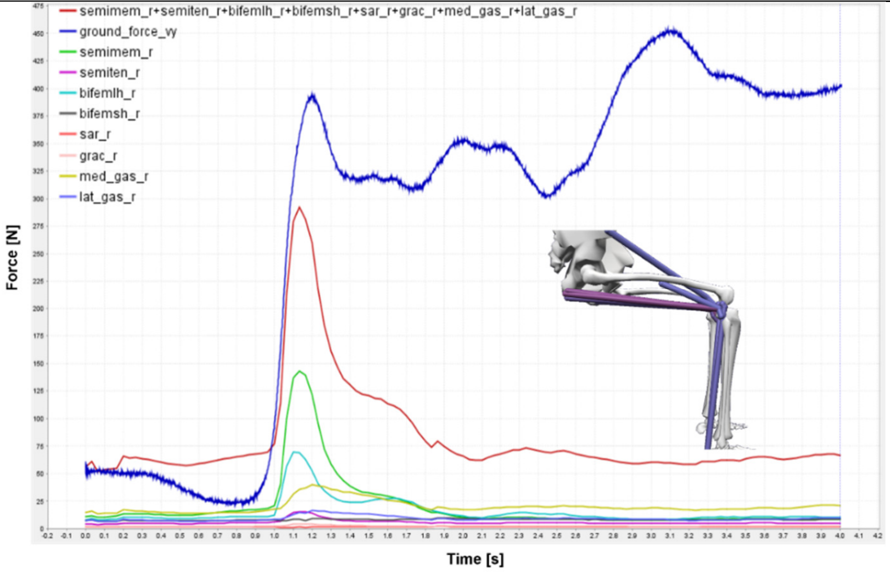
The simultaneous visualization of the experimentally determined vertical ground reaction force shows its correlation to the required muscle forces.



Extension of trunk



Extension of the hip joint



Flexion of the knee joint

Fig. 10. Calculation of muscle forces in OpenSim based on fbx-scan-data (test person 2).

As can be seen in the diagram above, the back extensors (Lumbar Erector Spinae) are particularly activated in the first phase of standing up. The maximum muscle forces determined for this are approx. 120 N each. In addition, for the extension of the hip joint (middle diagram), the muscle groups on the thigh (Semitendinosus, Biceps Femoris) and the Gluteus Maximus are used. The Gluteus Maximus muscle is one of the largest muscle in the human body and is the strongest extensor of the hip joint. All muscles of these groups exert a maximum force of 380 N (red curve). In addition to the muscle groups of the thigh, the lower leg muscles (Gastrocnemius), also known as the "calf muscle", are relevant for flexion of the knee joint. In the lower diagram in figure 10 it is shown that all muscles used for this purpose generate a maximum force of 290 N.
The results obtained are individual and can vary depending on the body weight and physical constitution of the test person analysed. They are the basis for the requirements-oriented design of the assistance system with stretch-resistant functional elements. These and other tasks are currently being finalised as part of the research project.

2.4. Material characterization of the textiles - clothing and functional elements

Various knitted fabrics are selected for the production of the basic functional clothing as well as elastic drawstrings for the realisation of the function. The textile-physical characterisations with regard to the stress-strain behaviour are carried out in accordance with the applicable standards (DIN 53835-14, DIN EN ISO 20932-3). For the base material, a knitted fabric made of 80% PES/ 20% Elastane is finally used (see figure 11, left). It shows a similar stress-strain behaviour in both main directions. Figure 11, right, shows the elastic properties of the functional elements (drawstrings). These are, on the one hand, a wide velcro tape fabric made of PA/PES/ZW/Monofil/EL (B1)and, on the other hand, a tape fabric made of PA/PES/natural rubber (B2).

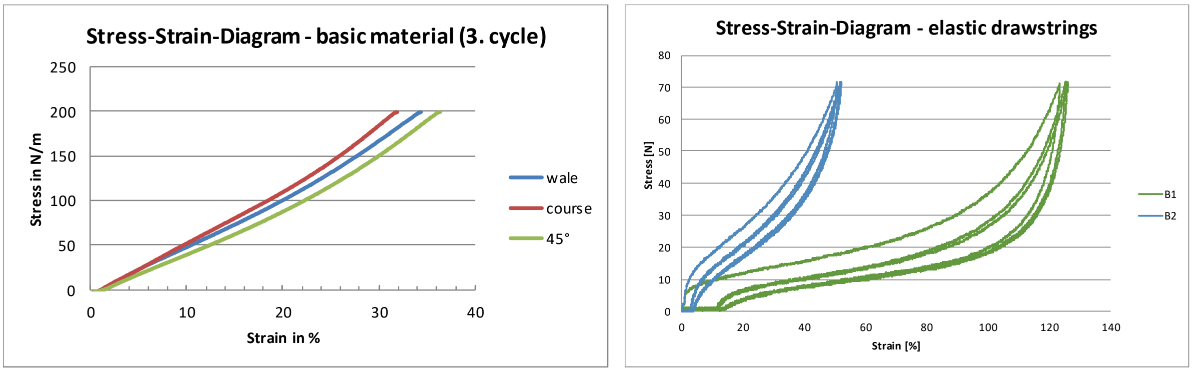
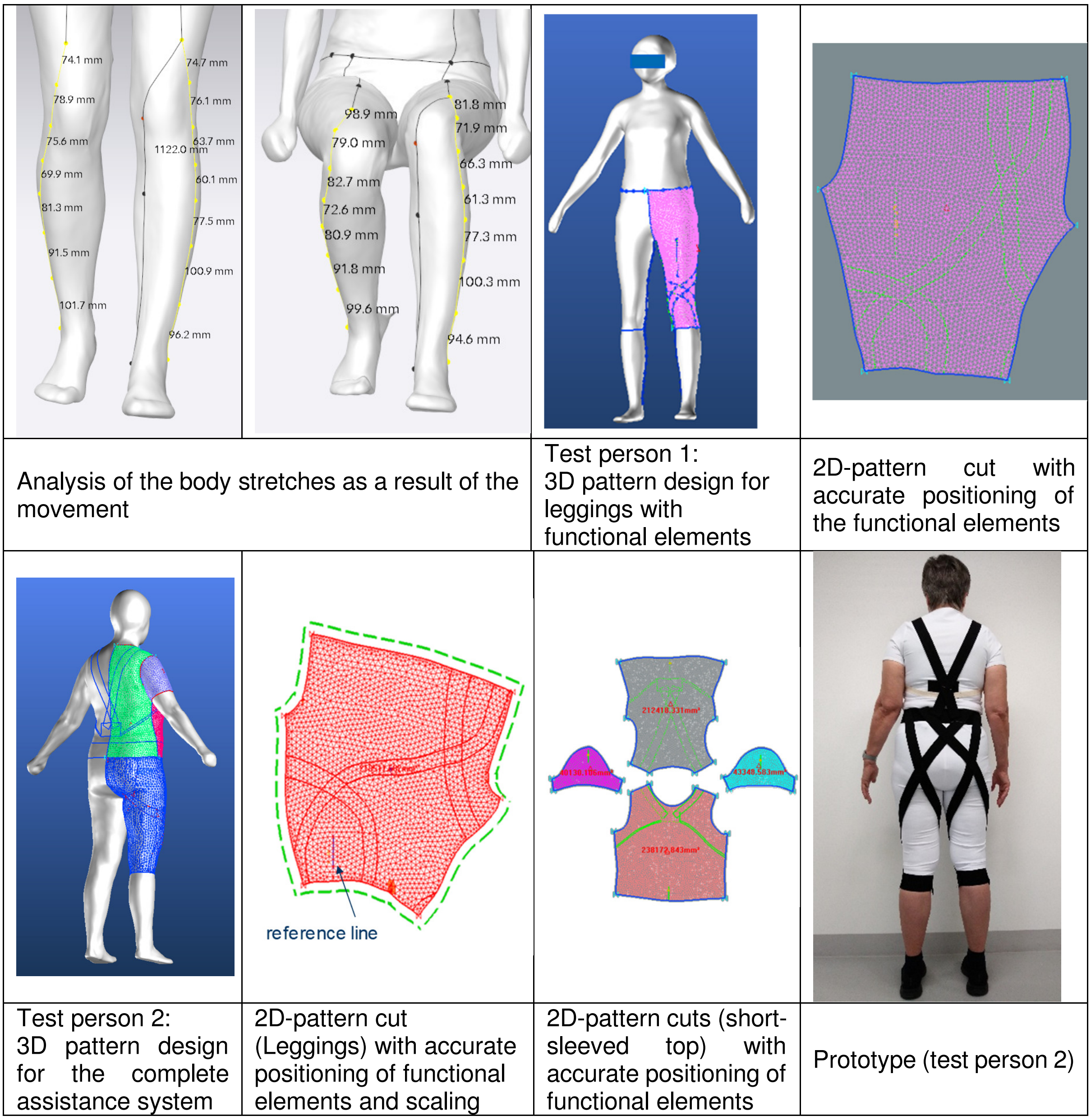


Fig. 11. Characterisation of the material to produce the prototype.

2.5. 3D construction and manufacturing of the prototypes

The individual pattern development and modification of the clothing assistance system is carried out on the basis of the respective 3D body data with the 3D CAD system *Designconcept 3D* from Lectra [13]. The design draft is drawn directly onto the body surface of the virtual model (see 2.1.). Within these pattern boundaries, the surfaces are meshed and flattened into the 2D environment by applying mathematical algorithms. The process is controlled by aligning the seam lengths as well as the surface contents. In addition, the material behaviour can be taken into account. For this purpose, the previously recorded stress-strain curve of the basic material is implemented into the software and the pattern cut is scaled accordingly in the circumferential directions. This is done on the basis of previous experience in the production of tight-fitting clothing, which are undersized. The expected wearing comfort and the fit can be virtually checked and corrected immediately afterwards. Figure 12 shows the 3D/2D pattern development for a short-sleeved top and leggings for the respective individual scan data sets.
The positioning of the functional elements in 3D to achieve the supporting effect is done depending on the previous analysis of body strains in motion. For this purpose, function lines (yellow color) with defined points are drawn on the body in standard posture in the *CLO3D* software [14] (see figure 12, above left). During the STS movement, the length changes between the points can be differentiated section by section. As a result of these investigations, the functional elements are positioned on the body lines/parts with the greatest length changes. Finally, the prototypes can be manufactured and are available for further investigations to validate the assistance effect.



Analysis of the body stretches as a result of the movement

Test person 1: 3D pattern design for leggings with functional elements

2D-pattern cut with accurate positioning of the functional elements

Test person 2: 3D pattern design for the complete assistance system

2D-pattern cut (Leggings) with accurate positioning of functional elements and scaling

2D-pattern cuts (short-sleeved top) with accurate positioning of functional elements

Prototype (test person 2)

Fig. 12. 3D/2D pattern development for individual passive assistance systems.

3. Results and validation

The result of this development is a passive exosuit. This suit presents as a allday functional underwear, suitable for wearing under normal clothes. The textile-based support of the defined STS movement is provided by stringent elastic drawstrings that store energy by stretching during the downward body movement (sitting down) and release it again during the upward movement. An electromyography (EMG) measurement can be used to determine whether the passive textile assistance system influences muscle activity and to what extent.

EMG measurements do not realise a direct measurement of muscle forces, but they enable the identification of changed muscle activity. This makes it indispensable for the targeted design of clothing assistance systems. The electrodes are attached to the skin and the potentials are measured during tension and at rest. The electrical potential recorded in an electromyogram during movement enables statements about the condition of the muscles.

For the defined STS movement, an EMG measurement was carried out for test person 1 with and without assistance system. The electrodes were attached to the muscle groups relevant for the defined movement (see figure 8). The results shows that for the STS movement less muscle activities is required for the test person in percentage terms by wearing the passive assistance system compared to the movement without support (figure 13). The savings range from 6% to 40%.

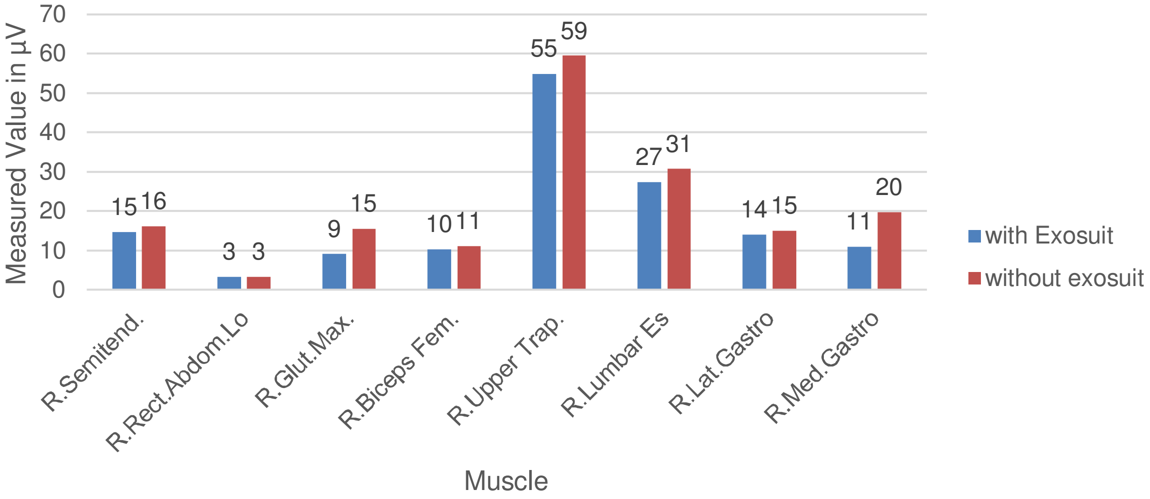


Fig. 13. Muscle activities in the STS-movement with/without passive exosuit.

4. Conclusions

In this paper, the process chain for the development of a textile passive assistance system to support older people with age-related limitations is shown. The aim is to relieve the musculoskeletal system, i.e. to reduce the forces required for an STS movement and to increase the stability of the movements. For this purpose, individual person data are scanned, textile materials of different strain stiffness are selected and characterised, the muscle forces to be supported are simulated depending on the defined movement, and the pattern design and the positioning of functional elements are carried out according to the requirements. EMG measurements show the supporting effect of the passive assistance system. It was seen, that the reduction of the detected muscle activity is between 7% and 40% for the relevant muscle groups.

In the future, they will thus represent a promising, user-oriented and everyday solution for supporting mobility without reducing the body's own strength and counteracting muscle degeneration.

Acknowledgment

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