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Book of Abstracts

3DBODY.TECH 2023

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3D Body Scanning and Processing Technologies

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OPENING SESSION

3DBODY.TECH 2023 - Introduction 00

Nicola D'APUZZO

Hometrica Consulting, Ascona, Switzerland

3DBODY.TECH 2023 - The 14th International Conference and Exhibition on 3D Body Scanning and Processing Technologies took place on 17-18 October 2023, in Lugano, Switzerland.
3DBODY.TECH 2023 was held as hybrid onsite+online event with conference and exhibition taking place simultaneously onsite at the Lugano convention center and live-streamed on the online conference platform. In-person onsite and/or remote online participation was possible for attendees, speakers, exhibitors.
This event was organized by Hometrica Consulting - Dr. Nicola D'Apuzzo, Switzerland.
3DBODY.TECH Conference & Expo, the premier multidisciplinary international conference and exhibition on 3D human body scanning and processing technologies, provides a platform of eminent professionals, entrepreneurs, academicians and researchers across the globe to present, learn and discuss the latest in 3D human body scanning and processing technologies.
The multidisciplinary character of 3DBODY.TECH makes it unique and not comparable to any other meeting related to 3D body technologies.
3DBODY.TECH Conference & Expo website 3dbody.tech gives all information related to this event.
The contents of the presented works at the conference are related, but not limited to, the following technical areas:
- 3D & 4D body and 3D & 4D face scanning methods, systems and technologies
- 3D body processing methods and technologies, 3D & 4D scan data processing
- 3D body modeling, 3D body visualization, 3D body printing methods and technologies
- 3D digital humans, virtual humans, avatars, metaverse
- Active and passive 3D scanning technologies for the human body (full body, bust, face, legs, feet, ..)
- 4D scanning, volumetric capture and MOCAP technologies for the human body
- Mobile/portable and hand-held human body scanning and measurement systems, devices, solutions
- Machine learning and artificial intelligence for 3D body scanning and processing
- Full body scanning and measurement systems for the apparel and fashion sector
- 3D virtual fitting, 3D digital fashion, 3D cloth simulation, virtual mirrors
- Applications in medical sciences (plastic surgery, orthotics, prosthetics, forensics, etc.)
- Foot scanning and measurement systems for footwear, sport and orthopedics
- Digital anthropometry, anthropometric studies, ergonomics
- Body measurement and sizing campaigns, fitting mannequins
- Biometrics and applications in security
- Applications in sport, health and fitness
- Applications in virtual life, games, FX and entertainment
- Applications in social sciences, and communication

These proceedings gather the papers presented during the conference by renowned experts in the field of 3D body scanning and processing. The technical papers are organized in theme sessions.
The website 3dbody.tech/cap is dedicated to the proceedings of the series of conferences and workshops on 3D Body Scanning & Processing Technologies and their contents.
The abstracts and papers of over 500 publications included in the proceedings of all conferences and workshops are available at the website and accessible from its different sections. The full papers are available for download as single documents (PDF), the entire proceedings in digital form (html structure and PDF filesm (html structure and PDF files).

TECHNICAL SESSION 1: Digital Anthropometry & Sizing Surveys

SizeWorld CHINA: Unveiling Evolving Body Shapes and Consumer Insights in the Chinese Market 10

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In a rapidly evolving landscape, understanding changing body dimensions and consumer preferences is paramount for manufacturers. SizeWorld CHINA, a collaborative effort between Avalution Germany, Human Solutions Germany, Humanetics China, and external partners, embarked on an extensive survey across six regions of China. This study aimed to capture and document the dynamic shifts in body measurements among men, women, and children aged 6 to 65+.

Through anthropometric measurements using state-of-the-art 3D body scanning technology and sociodemographic questioning, SizeWorld CHINA not only reveals significant insights into evolving body shapes but also unveils valuable consumer trends and preferences. These insights have far-reaching implications for different industries, for example necessitating the adaptation of size tables and design to cater to the current diversity of body sizes.
The results of the SizeWorld CHINA study will be made accessible through the iSize web portal, offering participating companies access to up-to-date body measurement data and analysis tools for targeted design and production. Join us for a concise overview of the study's key events and its impact and significance on the industry in general.

3D Scans of Toddlers and Kids - A Serial Measurement Survey 36

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Babies and toddlers have never been included in a serial measurement in Germany before. Accordingly, there has been no reliable size table to date. The last German serial measurement only provides data from size 116. It is generally known that babies and toddlers have very different body proportions than teenagers or even adults. However, reliable body measurements are essential for the product development of children's clothing. 5626 children (girls and boys) between the ages of 4 weeks and 18 years were recorded using the Vitus Smart XXL 3D body scanner whenever possible. Babies and toddlers who could not stand still were measured manually with the tape measure. From the scans, over 40 measurements were taken and 20 measurements were evaluated for the body measurement charts. For the development of the charts, sizes were first defined starting from body height. In a second step, body measurements relevant for clothing production and avatar generation were evaluated, e.g. back width, arm length, waist to sole and inner leg length. One focus here was the gender-specific consideration of body geometries. In the project, sizes 56 to 182 were described for the first time on the basis of real body data. Development stages were defined. These are: Babies Gr. 56-92, toddlers (unisex) Gr. 98-110 and children, differentiated into girls and boys Gr. 116-188. Factors such as diaper wearing and from when on body geometries differed significantly between the sexes contributed to the differentiation. These showed that boys adopt an upright posture significantly earlier, while girls start this process later. The new children's study and analyses of the project, as well as the newly developed avatars, have made it possible to create customized measurement charts, pattern and gradings suitable for children, and an optimal fit for babies, toddlers and teenagers. Important insights into the development of the child's body have been gained.

A Case for Standardization of Body Measurement Definitions: Investigation of Torso Girths 41

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Accurate body measurements are crucial for product design, particularly for developing clothing and equipment that must fit the body closely. Measurement's location and methodology of taking it must be defined unequivocally and precisely to successfully function as a determinant of the product's dimensions. Moreover, when working with multiple anthropometric data sets describing different populations, the measurements used for comparison must follow the same definitions. Key measurements are also used to develop product sizing and to communicate it to the consumer, as can be seen in standard EN 13402. Examination of anthropometric datasets and their documentation often reveals differences in terminology, measurement definitions, and/or methodologies used. Past research has documented the confusion related to the definitions of key torso measurements crucial for clothing construction (e.g. waist, bust, and hip). Such discrepancies can lead to errors in using the data and have implications for sizing and fit of mass-produced clothing.
The current study examined the documentation of four anthropometric studies and six sizing standards, focusing on the definitions of the largest torso girth measurements such as bust/chest and hip. Across sources, the discrepancies such as using different names for the same measurement or using the same name for different measurements appear to stem from assigning to a measurement one of several commonly used but not clearly defined words that refer to a particular area on the body. For example, for the lower torso, the terms hip (A1, A2, A3, S1, S2, S3, S4, S6), seat (A3), hip/seat (S5), buttock (A4), and maximum-girth-below-waist (A3) were used in reference to the girths at the locations of either (a) the widest part as seen from the front (A1, S1, S3), (b) the deepest part as seen from the side (A3, A4, S2, S5), or (c) the largest circumference (A2, A3, S4), with A3 using the terms hip and

seat interchangeably to refer to measurements at the same location, and S2 using a second combined girth based on both the front (abdomen) and back (buttock point) prominences.
Based on female body scan data from A3, Figure 1 presents the difference between the maximum girth below the waist and the girth at the buttock level (buttock prominence) and the distance of the maximum lower torso girth (above the crotch) from the buttock level along with the abdomen girth level as a reference. Findings show that for 32.8% (n=2069), 1.5% (n=97), and 65.7% (n=4143) of the sample (N=6309) the maximum girth was above, at, and below the level of the buttock girth, respectively, with the differences in the girths ranging from 0 to 13.7 cm (5.38 in), with an average of 1.9 +- 1.4 cm (0.77 +- 0.55 in). Differences of this magnitude can have implications for pattern construction (e.g. for placement of darts) as well as for sizing. For 52.5% of the sample, the maximum girth was larger than the buttock girth by 1.2 to 3.8 cm (0.5 to 1.5 in), or within the tolerance of the (typically) next clothing size up. Findings demonstrate that selecting measurements, identifying key torso dimensions, being precise in constructing measurement definitions, and being consistent in using agreedupon terminology is crucial to product design and sizing as well as communication. It is recommended that terms and definitions are standardized, communicated clearly, and used in a consistent manner across anthropometric studies and standards.

Analysis of Variance in Neutral Gaze Head Orientation During 3D Head Anthropometry Data Collection 22

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The Frankfurt plane head orientation is widely used in anthropometry research and anthropometric measurement definitions of the whole body and head. However, the authors believe that this head orientation may not be the best for head mounted extended reality (augmented, virtual and mixed reality) devices since it does not relate to natural product wear. When designing head mounted devices (HMDs), it is important to define head orientation, specifically pitch, related to how the device will be worn. In particular, these HMDs are often designed around the eye position with the head and eye in a natural, relaxed orientation - defined in this paper as the "Neutral gaze". However, the efficacy and repeatability of collecting this posture has not been thoroughly studied. The purpose of this study was to assess the variance of a repeated measures neutral gaze protocol. The primary research questions were: (1) What is the variance in neutral gaze within and between subjects, and (2) what are the largest sources of variance/error? Twelve subjects (four females, eight male) participated in this study. The data collection protocol was repeated five times per subject. Three anatomical landmarks were selected for their resistance to incorrect land marking and measurement - the Left and Right Tragion and the Sellion. Subjects were landmarked, performed a defined series of neck and shoulder stretches, and had their head scanned using a 3dMD head scanner. Following each scan, subjects stood up, walked up three sets of stairs, performed neck and shoulder stretches, returned to the scanning room, performed neck and shoulder stretches, and an additional head scan was taken. Head scans were digitized in 3dMD Vultus® providing coordinate point locations for the anatomical landmarks under study. This digitization process was conducted three times with proctor A and three times with proctor B to be able to assess intra- and inter-rater reliability. A "Neutral Gaze Vector System" was defined as a user-specified system, where the origin was defined as a point 3 mm in front of the Pupils at the midpoint between the Right and Left Pupil, the x-axis runs through the Right and Left Pupil, the y-axis runs vertically upwards, and the z-axis runs in the anterior direction. MATLAB was used to align all heads to this coordinate system. Variance and range for head pitch were calculated. The authors hypothesized five primary sources of variance: (1) anthropometry land marking, (2) position error of the participant, (3) scanning resolution at the pupil, (4) digitization error, (5) inter- and intra-rater reliability, and (6) MATLAB rotation/translation. Three of these five were investigated in this study. The results indicated the biggest sources of error to be: (1) positioning of the subjects and (2) digitization errors. The result of this work verifies the accuracy and repeatability of the neutral gaze protocol for a product related head orientation. This is especially important when performing such tasks as evaluating form and fit of subjects wearing head mounted devices.

TECHNICAL SESSION 2: 3D/4D Body Scanning Systems & Uses I

Should I Move to a 4D Scanner? 09

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Abstract not available.

Multi-Zone 4D Body Capture to Achieve 'Near Ground Truth' 3D-Detail of the Head, Hands and Feet 02

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Abstract not available.

Improvements in Mobile 3D Body Scanning and Body Measurements 07

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As mobile 3D body scanning continues to provide cutting edge solutions in creating made-to-measure garments and tracking body health and fitness, Size Stream has continued to refine its technology to deliver a smooth, user-friendly scanning experience and high-quality measurements. In this presentation, we present information about our latest mobile scanning solutions with new technologies leveraging the human silhouette boundary by using machine learning and computer vision techniques. We will provide quantitative analyses of the measurement quality of our latest scanning solutions, comparing them to our previous mobile solutions and larger booth-sized body scanners. Our analyses show that our new solutions provide faster and more accurate measurements of key body areas, including the waist, stomach, and collar, which are essential for the creation of custom-fit garments. Measurement performance is consistent across a wide range of body types and sizes, and body shape is more accurately represented in the 3D avatar. The result is a highly accurate and efficient method for capturing body measurements that can be used for a variety of applications in the fashion and apparel industry, including virtual try-on and sizing recommendations, as well as Size Stream's own made-to-measure garment construction.

Accuracy, Precision and Appearance of 3D Human Avatars Using a Mobile Phone 62

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Abstract not available.

TECHNICAL SESSION 3: 3D Body Scanning in Medicine I

Body 3D Reconstruction for Aesthetic Medicine 58

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We present a method to obtain a 3D reconstruction of the body, starting with the upper body but extendable to full body, in the context of aesthetic medicine, where anatomical accuracy is an important requirement. Our method uses a neural network to predict pixel-aligned implicit functions from three pictures taken with a commercial camera or cell phone. This allows us to capture geometries of arbitrary topology comprising everything from the chin to just above the knees, possibly including garments. The capture process takes seconds and yields sub-centimeter accuracy in the torso region without requiring specialized hardware.

Smartphone-Based Photogrammetry for Craniofacial 3D Modelling: A Preliminary Test 15

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Craniofacial 3D models are used for various purposes, such as cranial morphological analysis, surgery planning, and prostheses, among others. Today, three-dimensional (3D) scanners are commonly used to obtain 3D models of patients' heads. Similarly, there is a chance to apply mobile devices (smartphones and tablets) that implement photogrammetric techniques to build craniofacial 3D models. In this paper, a new photogrammetric solution to analyse cranial deformation, PhotoMeDAS (Photogrammetric Medical Deformation Assessment Solutions), is used to evaluate the quality of the system standalone or as part of an integrated photogrammetric pipeline.
Two preliminary results for achieving craniofacial 3D models with a current premium smartphone, the Samsung Galaxy S22, are presented. The first solution considered the Agisoft Metashape software which produced a dense point cloud and the textured craniofacial 3D model. The second result runs the mobile application PhotoMeDAS v. 1.7 to obtain a cranial 3D model of the same volunteer. The two

results were compared with a reference 3D model obtained with the white light 3D scanner Academia 50.
The photogrammetric 3D model obtained with Metashape allowed the visualization of the morphological characteristics of the volunteer's head and face, similarly as with the Academia 50, even though its processing time required extensive filtering. However, PhotoMeDAS was extremely fast and delivered pinpoint accuracy for the cranial area after just a few minutes of data acquisition and subsequent autonomous processing.

Prediction of Osteoporosis Site Using Artificial Intelligence: A Preliminary Study 16

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2 MINDS AND COMPANY, Seoul, South Korea

Osteoporosis is a systemic skeletal disease characterized by a decrease in bone density and abnormal microstructure, and as a result, bones become weak and fragile. If the site of bone loss is accurately predicted in advance by non-invasive methods such as bioelectric impedance analysis and 3D scanner, customized exercises for the site can be started earlier. Prior to model development using the 3D scanner we are developing, we studied whether it is feasible with an artificial intelligence (AI)-learned model using bioelectric impedance analysis data.
An AI model was built using retrospective data from 21328 subjects (2892 males, 18436 females). An AI model was built by extracting 23 features from a retrospective dataset of 21328 people (2892 males, 18436 females). The entire dataset was divided into a ratio of 9:1 between the train dataset and the test dataset. Ten percent of the train set was assigned to the validation dataset. As a result of building conventional machine learning models and applying 5-fold validation, the top 5 models were selected. For these 5 models, soft-voting ensemble was applied and the performance of the resulting model was evaluated by AUROC value.
Among the total study subjects, the proportions of the normal group, the spine bone loss group, and the hip joint bone loss group were 59%, 21%, and 20%, respectively. The top five performance models were Logistic Regression, LightGBM, Catboost, AdaBoost, and XGBoost. The AUROC results, which evaluated the performance of the five models using the test dataset, were 0.7508, 0.7479, 0.7455, 0.7365, and 0.7445 in Logistic Regression, LightGBM, Catboost, AdaBoost, and XGBoost, respectively. The performance of the soft ensemble result with the five models was AUROC 0.7544.
Through post hoc analysis such as SHAP value calculation and feature importance, we try to select features that are important for model learning. Through this, it will be possible to obtain which features to use in the 3D scanner we are currently developing to predict the site of bone loss.

3D Scanning in Forensics - The Virtopsy Project and the Future 69

Michael THALI

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Abstract not available.

A Reproducible Procedure for Individual Fitting in Orthotics and Prosthetics 71

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I will introduce multifunctional scanning devices that facilitate the division of labor and digital modeling in orthopedic labs.
Scanning in predefined or corrected position not just simplify the capture of patient shape but even support the whole design process.

TECHNICAL SESSION 4: 3D/4D Body Scanning for Apparel I

Quantitative Fit Assessment for Smart Gloves 11

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Fit plays an important role in the function and wearability of functional clothing. Smart gloves, or functional gloves with integrated technologies (such as sensors or actuators), rely on fit to create an interaction with the body surface that is needed to afford functionality. For example, glove fit must produce contact between a haptic actuator and the body to enable a haptic sensation. Failure of coupling between body and glove can also cause sensor malfunction, reduced mobility, and user

discomfort. High-resolution fit analysis is needed to assess the geometric relationship between gloves and the complicated anatomical structure of the hand. This study developed a high-resolution fit assessment method that provides quantitative information on smart glove fit. The study defined key fit measures, proximity and alignment, to measure smart glove fit, focusing on quantifying the relationship between integrated technologies and the body surface. A quantitative pipeline was developed that included three stages: hand model development, 3D scan analysis, and result translation. The methods provided high-resolution (< 1 mm accuracy) and objective data that can be used to inform smart glove fit improvements and, consequently, improvements to on-body functionality. The results of the fit analysis demonstrate that these methods can effectively quantify glove fit. Adding proximity and alignment measurements to the analysis allows the relationship between the body and integrated technologies to be quantified, providing information to improve smart glove fit. Virtual fitting was explored for expanding the pipeline to reduce prototyping time and costs by simulating gloves virtually.

Investigation of the Interaction between Protective Clothing and Body During Motion Actions with Integrated Multisensory Scanning System 4Dsense 21

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In times of societal change toward an environmentally conscious and sustainable community, bicycles are increasingly becoming the key to personal transportation. Bicycling and other high-speed sports such as soccer, field hockey, and volleyball often result in abrasions. These occur through the dual mechanisms of friction and shear forces. To avoid this, protective elements are usually integrated into the sportswear at the joints. However, since the joints are always the point of maximum garment displacement, accurate placement of the protective elements is an important prerequisite for the protective effect. The objective of this work is to investigate the extent to which relative displacement occurs between the joint and the protective element during typical application movements.

For achieving this objective, different types of sensor techniques must be applied simultaneously. The complete system, named 4Dsense was build on the basis of the Move4D scanner (produced by IBV) for photogrammetric scanning, which was integrated with the electromagnetic VIPER System of company Polhemus for direct absolute position tracking and with pressure measurement system TexSens-G. 4DSense provides information about the motion of the clothing or the human surface, the coordinates of several points under the surface and the pressure between the clothing and human body on selected positions. The first results of the application of this multi-sensory system 4DSense for the investigation of protective clothing shows that the combination is very promising and provides information with additional dimensions and quality, which will help the clothing developers to provide protective clothing with improved wearing comfort during motion.

A Statistical Size Recommender for Safety Footwear Based on 3D Foot Data 40

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Shoe size recommendation remains a significant challenge for the footwear industry. Getting a shoe that does not fit leads to customer dissatisfaction and high return rates. In the case of safety footwear, this challenge is even greater because wearing the wrong size can compromise the safety of workers. It is thus crucial to develop a technology that allows industry to efficiently provide their employees with the right shoe size advice, in a fast, simple, and effective manner. This paper describes the results of the joint cooperation between IBV and Base Protection S.r.l. to develop and deliver such a system.

The proposed technology uses low-cost 3D scanning technology (Domescan/IBV and 3Davatar feet) to accurately capture 20 foot features and a shoes size recommender based on Multinomial Logistic Regression (MLR). The system was trained for 14 shoe lasts and used data from fitting tests of 60 subjects from both genders. It was validated with fitting tests of 25 subjects achieving an 60-80% success rate in recommendations, depending on the shoe model. The results also showed that personal fit preference plays a crucial role in size selection, hindering greater accuracy. In this regard, one of the main advantages of MLR is its informative output, i.e. a map of fitting probabilities for each size, which offers multiple options for the development of the user interface layer and may enable that the final consumer to make an informed decision based on it. The system also included an insole recommender (low, mid and high arch) that uses a classic two-dimensional recommendation grid based on foot arch indexes based on three foot features. These technologies were embodied into a

physical booth for brick-and-mortar stores and into an app that directs the consumer to the nearest point of sale. This system represents a significant advance in the footwear industry and offers a streamlined solution for brands and retailers. Overall, this work demonstrates the effectiveness of utilizing MLR in a footwear recommender system, and highlights its potential for footwear brands and retailers to reduce returns and increase sales, for consumers to get a better comfort and safety at work, and for industries needing for safety shoes to reduce the burden of managing the footwear orders to its employees.

Understanding Clothing Insulation with Help of Virtual Tools - Case Study of Fire Fighter Clothing 63

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Both the physical properties of the fabric materials used in clothing and the effective design of the clothing, primarily in terms of the air gap thickness, restrict the transmission of the thermal energy from the heat source to the firefighter's body. The air gap distribution over the body in real deployment conditions of firefighters will vary, The knowledge of local clothing properties in real-life exposure provides a true protection mapping and gives design inputs to improve the local protective properties of firefighters' clothing. To explore the distribution of air layers in complex multi-panel and multi-layer firefighter clothing we used the CLO3D software to visualize the the air layer distribution across the clothing thickness and related it to the thermal resistance property. One of the findings suggested that the stiffer the outershell of the firefighter jacket, the more balanced the distribution of air layers between inner layers leading to higher total thermal insulation. The devised methodology has been systematically validated using 3D-scanned data for multilayer garments with different level of complexity. The findings of this study are being used for optimization of thermal properties of firefighter protective clothing.

TECHNICAL SESSION 5: 3D/4D Body Processing

Comparative Analysis of Tools for Processing 3D and 4D Scan Data to Study Deformations in the Human Body 19

Ann-Malin SCHMIDT, Yordan KYOSEV

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Methods for capturing human body motion and deformation are constantly evolving. In order to analyse human body deformations, it is necessary to capture the body surface by performing a 3D or 4D scanning process.
Various tools for processing and analysing 3D and 4D scan data are available as open source and commercial software. These software and programming languages are compared. Therefore, an overview of commonly used scan data output files is described. Scan data analysis parameters for body deformation analysis are presented. Different software is compared with respect to these parameters. Finally, a self-developed framework for automatic scan data analysis is described. By using the presented framework, the processing of scan data can be made more efficient, thus making a valuable contribution to the development of realistic human models.

Challenges We Faced (and Are Facing) in Implementing an Automated Solution for Digital Anthropometry 44

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Digital Anthropometry's Significance:
In the ever-evolving landscape of technology-driven solutions, the realm of digital anthropometry has emerged as a pivotal field with vast implications for various domains, from healthcare and fashion to ergonomics and biometrics.
This tech paper delves into the intricacies of 3D anthropometric measurements, providing a comprehensive framework for accurate and repeatable data acquisition for these diverse purposes.
About 3D Measure Up:
We begin by introducing the context of Sisyphius and Proteus, highlighting the importance of precise anthropometric data in various applications.
The paper further focuses on the innovative, cutting-edge 3D Measure Up system that combines advanced scanning techniques with intelligent algorithms to provide accurate and precise

measurements.
Digital Anthropometry Pipeline:
The Digital Anthropometry Pipeline, which comprises several critical stages: Pose, Capture (2D/3D), Analyze the mesh, Preprocess, Measure, Validate, Export, and Share.
Address Digital Anthropometry Challenges:
Furthermore, the presentation addresses the challenges of digital anthropometry, discussing factors such as:
1. Analyzing the input mesh to fine tune the measurements: This diagnostic process encompasses several crucial aspects: Posture detection and dependency; Scan measurement unit; Scan orientation/alignment; Scan quality - holes, stray meshes, rough surfaces, self intersecting meshes; Scan of full body, partial body; Scan size and resolution; Scan with multiple meshes; Scan rigged with skeleton
2. Scan quality: Scan with blurred faces; Incomplete scans - cut feet, hand/palm; Scans with background and platforms; Scans from old scanner versions.
3. Bone based landmarks: Adams Apple: Present in Men, Absent Female, Difficult to detect in Obese; Shoulder: Sloping shoulder, Square shoulder, Rounded shoulders, Scoliosis; Waist v/s Trouser waist; Measuring the Neck: Axis of the neck, Shapes of the neck, Hairy challenges
4. Identifying the Navel landmark: Scan of a clothed person; Shape of the abdomen
5. Leg and Arm: Left and Right Leveled or Actual
6. Aligned to skeleton: Determining the axis of skeleton; Identifying the section boundaries; Identifying the axis of the section
7. Measuring obese bodies: Trouser Waist; Navel point
8. Accuracy: Verifying accuracy of the Measuring tool/software; Verifying accuracy of the scan; Solution to access accuracy
These diagnostic steps are vital prerequisites to ensure the accuracy and reliability of subsequent measurements and analyses conducted on the scan data.
At the core of its capabilities, 3D Measure Up is designed to seamlessly take input from any scanner (handheld, turntable, booth, Lidar), allowing for compatibility and flexibility in the scanning process.
Once the scans are acquired, 3D Measure Up takes charge, acting as a centralized hub for storing, collecting, visualizing, and refining the measurements.

Building Novel Dynamic Pattern Theory via 3D Body Scanning Data 45

Simeon GILL 1, Carol MCDONALD 2, Katy SCHILDMEYER 3, Dana TODD 4,5

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Is it possible to build a well-fitting and functional pair of pants “from the ground up” via a 3D scan of a human? Body scanning provides opportunities to build more robust body-to-pattern drafting and product design theories. The practices provided can allow garment pattern blocks to be defined with much clearer relationships to the body, using body regions and understanding of body shape and fit requirements. However, the current technology for body scanning merely replicates existing practices for sizing or product development measurement, with little focus on how this technology can significantly and accurately evolve computer pattern drafting practices. This research explores how enhanced data coming from body scanning can support pattern blocks for trousers which are developed more uniquely to the body, enhancing both ready-to-wear and made-to-measure market needs.
Body measurement files and OBJ scan files were collected using multiple leading mobile scan brands. The challenges of validating and verifying the measurements utilizing the OBJs are discussed. The issues fell into two main categories: variance of measurement definitions and techniques, and the geometry of the mesh itself. The geometry of mesh can lead to approximations of measurement locations which have an impact on pattern drafting. The uses of the OBJs beyond visual representations are presented.
Applying novel measurement extraction techniques to OBJ scan files, this research uses Rhino and Grasshopper software to extract measurements that drive a parameterized trouser pattern. Clearly-defined requirements were set for extraction, and the parametric block was established in Seamly2D® open-source pattern cutting software.
This research illustrates the advantages of using novel approaches and enhanced measurement techniques to develop pattern theory that uniquely reflects the body size, shape, and proportion of the

wearer. By identifying novel usage of data to drive the pattern, it is possible to address fit requirements, illustrate clear benefits of body scanning, and define how the application of technology can evolve pattern drafting practice to allow better engineered garment fit.

3D Body Scanning Applied for Human Torso Evaluation 27

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Anthropometrically, humans are considered more-or-less bilaterally symmetric. However, several micro and macro factors perturb the symmetric nature of humans and other living organisms. Typically, human asymmetry may be quantified by measuring the individual components on either side of the body, i.e., right versus left arm length. This matched symmetry approach relies on specific landmarks. Though this is a valid method, the matching symmetry approach is not viable for the 3D torso because a torso's right and left sides cannot be separated precisely by a single plane when it comes to the human torso. Researchers have attempted to look for a single plane that volumetrically divides a human body based on the general assumption that the human body is bilaterally symmetric. In reality, the human body is a three-dimensional object that needs to be perfectly symmetric for such a plane to exist. However, the majority of human body shapes exhibit asymmetry of various degrees. Here, a novel non-invasive method is shown for estimating the rate of asymmetry in the 3d human torso using 3D body scanning technology and mathematical methods. The proposed method computes the asymmetry of a human torso by iteratively estimating localized symmetry in small 2D slices of torso scans and combining them to determine the global symmetry/asymmetry. 3D body scans of 30 subjects (15 males and 15 females) were used in this study to develop and evaluate the method. Here, the torso was defined as the upper part of the body from the cervical to the crotch-level, with hands removed at axilla point posterior left and right. The mathematical computations used the MATLAB programming tools. The developed method quantifies the degree of asymmetry on the human torso. The method is suitable for 2D and 3D surfaces and can compute asymmetry from 3D scans and other types of digital models. The technique has potential applications across various fields.

TECHNICAL SESSION 6: 3D/4D Body Scanning Systems & Uses II

The Advantages of Real-World 4D Human Data Use Over Synthetic Data for Advanced Human Factors and AI-Driven Human Perception Applications 03

Andrew AUBREY, Kelly DUNCAN

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Abstract not available.

A Primer on Volumetric Video by Arcturus 66

Kamal MISTRY

Arcturus, Los Angeles CA, USA

Abstract not available.

Volumetric Capturing with Emergent Vision Technologies - From Pixel to Reality 37

Thomas DETJEN

Emergent Vision Technologies GmbH, Kernen im Remstal, Germany

Join us in Lugano as we peel back the curtain on the transformative power of our pioneering camera technologies at the 3D Body Tech Conference & Expo!
Gain exclusive insights into a versatile setup, scalable from head-only to full-body capturing, and designed to evolve alongside your expanding demands.

4D Scanning and Volumetric Capture - Introduction and Technical Overview 01

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4D Scanning and Volumetric Capture are two advanced performance capture techniques being used today to create life-like digital representations of real human actors. These are similar but different approaches; both make use of synchronized multi-viewpoint camera systems to generate source material, and both use photogrammetry processing techniques to produce textured 3D models at video frame rates. The workflows from there and how the content is used is what sets these two techniques apart. This short overview will cover the basics and technical details, as well as information about the hardware and software components being used in professional systems today.

The Scan Truck : Premier Mobile 3D Capture Solutions 64

Jiggs LOVE, Vlad GALAT
The Scan Truck, Los Angeles CA, USA

Abstract not available.

TECHNICAL SESSION 7: 3D Digital Humans, Avatars, Body Modeling

FLSH - Friendly Library for the Simulation of Humans 20

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Computer models of humans are ubiquitous throughout computer animation and computer vision. However, these models rarely represent the dynamics of human motion, as this requires adding a complex layer that solves body motion in response to external interactions and according to the laws of physics. FLSH is a library that facilitates this task for researchers and developers who are not interested in the nuisances of physics simulation, but want to easily integrate dynamic humans in their applications. FLSH provides easy access to three flavors of body physics, with different features and computational complexity: skeletal dynamics, full soft-tissue dynamics, and reduced-order modeling of soft-tissue dynamics. In all three cases, the simulation models are built on top of the pseudo-standard SMPL parametric body model.

Skinning Weights Optimization through Data-Driven Approaches: Determining the Training Dataset 29

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Junfeng PENG 2, Xuguang WANG 1
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Skinning methods that employ skeleton-driven deformation for predicting human skin shapes in different postures are widely utilized in computer graphics applications, but also in ergonomics-related applications for products and clothes development. In these methods, a hierarchical bone structure is used to drive the transformation between postures of the vertices compositing the skin mesh. The vertices are influenced by the underlying bones according to their skinning weights. The skinning weights can be defined from manual painting, purely geometric methods, or solving heat diffusion equations among others. Data-driven approaches use large amounts of data to determine the skinning weighs: 64000 multi-pose and multi-identity body scans were used in [1], 1786 multi-pose meshes from 40 subjects and 3800 multi-identity meshes were used in [2], and 237 meshes from 50 subjects were used in [3]. Even though it's well-known that numerous training skins are required to produce accurate results, the sensitivity of the results to the amount and type of training data has not been investigated. For this reason, this work studies the influence of the composition of the training dataset (numbers and type of subjects and postures) on the determination of the skinning weights. The quality of the skinning weights was performed by analyzing the predicted skin shapes and 3D scans in the final postures considered as ground truth data. The results of this study can be of interest for the definition of databases used to develop data-driven models to predict shapes in new postures; especially considering the costs associated with data collection campaigns.

Neural Approaches for 3D Pose Estimation from 3D Data 42

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Understanding human pose is a fundamental component of many forms of art, including sculpture, painting, drawing, and animation. Software that can accurately capture and represent the human pose is essential for creating realistic and expressive works of both traditional and digital art. However, to the best of our knowledge, there is currently no open-source code available for deep learning-based pose estimation from static 3D data. While there exist many "classical" pre-deep learning methods for this task, they have a significant drawback: they are not differentiable, making them difficult to incorporate into subsequent deep learning pipelines. We put special emphasis on integration with deep learning pipelines since they are the cornerstone of modern creative systems. In this work, we propose and implement two methods for human pose estimation based on neural networks. The first method leverages part segmentation to classify the body part of each point and estimates the body joints

based on neighboring parts. The second method estimates joints directly from point clouds. Our code will be made available on GitHub.

Meshcapade's Digital Human Platform 06

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Abstract not available.

TECHNICAL SESSION 8: 3D/4D Body Scanning for Apparel II

Deep Disruption: Changing the Fashion Industry through Made-to-Fit Garments 32

Andreea BUNICA, Nathan HUNTOON

The Fitting Room, Toronto ON, Canada

The paper presents a new technology that enables the production of custom fit, made-to-order garments central to the product of fashion-tech start-up The Fitting Room (TFR). TFR is focusing on disrupting the fashion industry through intuitive virtual try-on and made-to-fit products.

The fashion industry is one of the top polluters globally, producing approximately 3% of global carbon emissions, and generating millions of tons of waste every year. Complex supply chains, overproduction, and high return rates are leading causes of this waste. Virtual Try-On (VTO), is slowly proliferating through the industry, is an initial attempt at using technology to diminish the rate of returns generated by online shopping. VTO is an entry point, but deeper industry restructuring is required to meet the ESG goals of the fashion industry. From a market structure point of view, the rate of returns represents the tip-of-the-iceberg problem: the issues run a lot deeper, starting with dis-informed production and shorter garment style life-cycles. In order to satisfy the demand for more styles, while cutting down on over production and waste, the industry must transition from mass production to a made-to-order on demand production model.

Recent advancements in high fidelity 3D body models from pictures and video have enabled consumers to create digital twins ready for use in custom clothing design. TFR is funneling this new technology to the market, combined with an algorithmic approach to garment customization (Made-to-Fit), and a software-as-a-service (SaaS) supply chain, to enable any designer to offer custom sized clothing, made-to-order, directly from their e-commerce platform.

The challenge of the Made-To-Fit (MTF) algorithm is to parametrically scale an original fabrication-ready garment pattern to fit a customer exactly as intended to a "fit model" and to then generate a cohesive Tech Pack for mass customized production.

In traditional manufacturing, designers use a "fit model"- a standard body that is used for taking measurements- in order to design a garment and to produce its affiliated production pattern. A garment perfectly fitted on the "fit model" can then be graded and scaled to obtain multiple industry-standard sizes. The MTF algorithm's task is beyond simply automating pattern generation- the task involves parametrically generating infinite patterns that can be tailored with precision to as many body types as possible. The challenge is to extract the exact fit map that the designer intended in the original design, but to scale it to the body of individual customers. The knowledge required to generate a functional parametric scaling model does not translate from traditional pattern-making, as there are no parallel tools in the physical world to fulfill a mass customization task that outputs tailored garments. Made-To-Fit is a computer-specific problem.

How Does Customers' Fit Preference Impact Apparel Size Selection for Online Shopping? 60

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E-commerce has become part of our lives with the number of online shopping transactions rising steadily, while selling clothes online is still challenging greatly due to uncertainty on size and fit selection. Return rate in the textile industry in general is reported between 20% to 40%, which has an enormous financial and environmental impact for retailers and the planet. Many efforts have been made in the past to develop new technology to create accurate 3D humans by mobile phone. However, only knowing the 3D shape of customers is not enough to have an efficient size recommendation tool. How to match the multiple types of personal information, like body shape, preference and potential usage as well as the sizes of the products is less investigated in literature. In this study, an experiment of 175 female participants with different body shapes from XS to 4XL on 6 garment top products was conducted. The collected personal information included not only their body shape, measured by a 3D body scanner and manually par two experimenters, but also their fit preference and practice usage.

For each product, they were required to test different sizes to choose their preferred size as it was a purchase in a physical store, and also evaluate a bigger size and a smaller size than the preferred size to check if they would return it in an online shopping scenario. The participants were divided into three groups according to their preference. The first results of the study showed that the fit preference has a significant impact on the size choice. As expected, the data confirmed that independent from the body shape, the participants who declared preferring a loose fit have more chances to choose a bigger size than the theoretical size compared to the group of "adjusted" and "regular" fit. The difference is even more important when it comes to the product with less elasticity, like a jacket. Future research is needed to explore how to integrate the preference information into a size recommendation algorithm, together with body shapes of customers and dimensions of products.

Predicting Human Body Measurements Using MediaPipe Pose Auto-Capture 33

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Anthropometry plays a crucial role in understanding the human body and its variations, contributing to advancements in various fields such as health, sports, and design. However, the current practices for identifying human body shapes for apparel production and design are limited. This study aims to address this gap by utilizing MediaPipe Pose to recognize human body measurements based on front and side poses, laying the foundation for a novel clothing sizing system. We used MediaPipe's framework for auto-capturing poses and visual recognition to identify human body outlines. The width, depth, and height of the shoulders, chest, waist, and hip were calculated based on user input height. The body scan comparison from the pilot test data suggested that the captured outline tended to underestimate widths more than depths, particularly for the female subject. Future studies may collect and manually verify a large amount of picture data and corresponding body data to develop an AI model for human body shape categorization.

Approach for Digitizing the Softness of Human Tissue for Implementation in 3D Soft Avatar Clothing Simulations 59

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Patterns are virtually simulated in 3D CAD programs before production to check the fit. However, achieving lifelike representations of human avatars, especially regarding soft tissue dynamics, remains challenging. This is mainly since conventional avatars in garment CAD programs are simulated with a continuous hard surface and not corresponding to the human physical and mechanical body properties of soft tissue. In the real world, the human body’s natural shape is affected by the contact pressure of tight-fitting textiles. To verify the fit of a simulated garment, the interactions between the individual body shape and the garment must be considered. This paper introduces an innovative approach to digitising the softness of human tissue using 4D scanning technology. The primary objective of this research is to explore the interactions between tissue softness and different compression levels of apparel, exerting pressure on the tissue to capture the changes in the natural shape. Therefore, to generate data and model an avatar with soft body physics, it is essential to capture the deform ability and elasticity of the soft tissue and map it into the modification options for a simulation. To aim this, various methods from different fields were researched and compared to evaluate 4D scanning as the most suitable method for capturing tissue deformability in vivo. In particular, it should be considered that the human body has different deformation capabilities depending on age, the amount of muscle and body fat. In addition, different tissue zones have different mechanical properties, so it is essential to identify and classify them to back up these properties for the simulation. It has been shown that by digitising the obtained data of the different defined applied pressure levels, a prediction of the deformation of the tissue of the exact person becomes possible. As technology advances and data sets grow, this approach has the potential to reshape how we verify fit digitally with soft avatars and leverage their realistic soft tissue properties for various practical purposes.

TECHNICAL SESSION 9: 3D/4D Body Technologies for Health & Sport

New Body Composition Metrics from Size Stream 3D Body Scanning 31

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This paper describes the development of a group of body composition metrics derived from 3D body scan measurements. Traditional metrics such as body mass index (BMI) have limitations in accurately reflecting body composition, especially for athletes and individuals with higher muscle mass. Size Stream has previously presented the development of body composition metrics such as body fat percentage, lean body mass, maximum waist circumference, and waist to hip ratio. These metrics are well established in the medical literature as being indicators of unhealthy risk conditions at certain values. Here we present new developments for appendicular lean mass, body mineral content, and visceral adipose tissue which also have recognized value in body assessment. The proposed metrics utilize 3D body scans to capture detailed information on body shape, surface area, volume, and other body measurements. Machine learning algorithms were used to develop the new metrics, which were created leveraging the established body composition assessment method of dual-energy x-ray absorptiometry (DXA). The new metrics show correlation between 3D body scan measurements and the ground truth data. These added metrics have the potential to improve body composition assessment and monitoring in clinical, sports, and research settings with convenience and low cost afforded by 3d body scanning using smartphone and tablet applications.

Mapping the Body to Screen for Clinical Health Conditions and Athletic Prowess: Implications for Health Literacy and Athlete Identification 38

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For centuries, scientists have used anthropometric techniques to measure and map the external dimensions and proportions of the human body. It has become evident that the shape of the body provides a map to its internal state and performance. For instance, measuring waist circumference to assess android obesity has revealed direct links to the development and risk of various chronic health conditions, including: cardiovascular disease, type II diabetes, and non-genetic cancers. Waist circumference is just one of many anthropometric parameters clinicians can use to non-invasively screen high risk individuals, enabling the implementation of timely preventative health interventions. On the other end of the spectrum, anthropometric measurements have been used to assess and predict sports performance. Limb lengths, girths, body composition, and various other metrics may be used as indicators of an athlete's physical capabilities allowing coaches, trainers, and sports scientists to evaluate an athlete's strengths and weaknesses for athlete identification, tailor training programs, and optimize athletic performance. The analysis of anthropometric data does far more than predict disease risk and human performance, it also empowers the patient or athlete with a better understanding of their overall health and athletic strengths. Thus, by providing an accurate and precise means to map and measure the body, patients and athletes may demonstrate an improvement in health and performance literacy. Artificial Intelligence (AI) has significantly enhanced the field of anthropometrics through the development of 3D Optical Imaging (3DO). Using 3DO, clinicians and coaches alike now have a non- invasive and efficient means to gain valuable insights into both clinical conditions and sports performance. Ultimately, this screening technology has further implications for improving health literacy and individual well-being as well as sports performance optimization.

Dynamic Scanning of Cyclists: Techniques and Applications 52

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2 ITM, TU Dresden, Dresden, Germany

Technological advancements in human body modelling have experienced significant growth in recent years. A prime example is the MOVE4D system by IBV. This system combines scanning and post-processing techniques to generate watertight 3D meshes of the human body in motion, thereby opening up numerous possibilities and applications in various fields, including the analysis of anthropometric features on the articulating human body. One limitation of the MOVE4D system is that it is unable to create watertight meshes when a subject and an object are scanned together. This issue arises when registration techniques used on a homologous mesh yield deviations from the true shape

of a human, with the initial point cloud containing an articulating human together with points of an object supporting the articulation. This bottleneck is currently limiting further exploration of object-assisted human movement, as applied in fields including sports sciences and occupational ergonomics. In this study, a subject is scanned while cycling, at a rate of three frames per second, to present a technique that discards the bicycle and captures only the human subject. The resulting avatar of the cyclist is a valid representation of the articulating cyclist. Discarding the bicycle is achieved by using an infrared- absorbing black coating on a bicycle template that successfully inhibits the MOVE4D IR camera's ability to capture the bicycle template. In addition, the specific very low surface area of the geometry of the bicycle template allows the MOVE4D system to accurately capture the cyclist's body in its entirety. This coating yields very promising results that could not be achieved with the other option explored in this article: removing the bicycle algorithmically through a post-processing step. Two initial applications of our technique are presented, demonstrating how to retrieve dynamic anthropomorphic features and aerodynamic drag simulations.

TECHNICAL SESSION 10: 3D/4D Body Scanning Systems & Uses II

Revolutionizing Intelligent Sizing with Esenca's AI Body Measurement Solution 54

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Abstract not available.

Real-time Photogrammetry 3D Scan of Body Parts for Smartphones 14

Olivier SAURER

Astrivis Technologies AG, Zurich, Switzerland

Introducing real-time photogrammetry 3D scanning technology for iOS and Android devices. Scan human body parts (e.g., face, leg, foot) with the highest privacy using local computing, delivering rapid, instant 3D model results on your phone. This technology extends beyond scanning, allowing for the capture of 3D measurements, making it suitable for various practical applications.

Scanning Head Avatars in the Wild - Challenges and Applications 55

Titus LEISTNER

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Abstract not available.

TECHNICAL SESSION 11: 3D Body Scanning in Medicine II

3D Scan to Knit - Workflow and Challenges of Automated Data Processing and Knit Program Generation for Prosthesis Liners 56

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This work presents the current development state of an automated algorithm for creation of knitting instructions for prosthetic liners directly from 3D scan data. This is a knitted medical textile worn by amputees, which on one hand mediates between the residual limb and the prosthesis and at the same time has to ensure appropriate protection and hygiene. Although the shape of the residual limb is very individual, liners have so far been manufactured in standard sizes. In the presented case, 3D scanning is used to obtain the geometry of the residual limb. The raw data is cleaned and adjusted manually and prepared for automated processing. The algorithms for slicing and preparing the intermediate knitting instructions are developed in Python language, using several functions inside of the open-source software Blender. The information for the loops of the knitwear is saved in intermediate bitmap (knitting chart), which is finally imported in specialized software for knitting machine design and used for the generation of the final program.

A Comparative Study of the Sagittal and Coronal Plane Balance of the Spine Measured Using a 3D Full Body Scanner and Spine X-Ray 18

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With the aging of the population, adult spinal deformity (ASD) caused by degenerative changes in the spine, is becoming increasingly common. Accurate measurement of spinal balance is required for the diagnosis and treatment of ASD. Currently, the analysis is mainly conducted using X-rays, but there are limitations such as radiation exposure and difficulty in reflecting actual daily postures. On the other hand, radiation free 3D scanning method for the body surface developed with technological advances. The purpose of this study is to compare the efficacy of 3D body scanner analysis and conventional x-ray analysis in measuring ASD.

Correlation between Low Skeletal Muscle Index and 3D Anthropometric Data of Lower Extremities Measured by 3D Body Scanner 26

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SMG-SNU Boramae Medical Center, Seoul, S. Korea

Background: The initial screening test for sarcopenia is performed by measuring the circumference of the calf (CC). However, the circumference measurement has the disadvantage of being inaccurate depending on the measurer and the measurement method. This study aims to confirm what factors can be used for the initial screening test for sarcopenia in the 3-dimensional anthropometric data of the lower extremities and what the cut-off value is.
Methods: From October 2022 to February 2023, we retrospectively analyzed the results of 3D human body scanner measurement and bio-impedance analysis for patients aged 50 to 80 at risk of Sarcopenia. The 3D human body scanner results measured the surface and volume values of both thigh, and calf. In bio-impedance, the presence or absence of sarcopenia was confirmed by the SMI value. Statistical differences in surface and volume values of the thigh and calf according to the presence or absence of sarcopenia were confirmed, and receiver operating characteristic (ROC) analysis was analyzed for statistically significant values.
Results: Sarcopenia was present in 6 out of 62 subjects with an SMI value of less than 5.7. Compared to non-sarcopenic patients, sarcopenic patients showed significantly lower values of right, left and the mean calf volume (right calf volume 2.62m2 vs 3.34m2, p 0.033; left calf volume 2.62m2 vs 3.25m2, p 0.044; mean volume of both calf 2.62m2 vs 3.29m2, p 0.029). Also, the mean surface of calf showed statistically lower value on sarcopenic patients (mean surface of both calf 0.12m2 vs 0.13m2, p 0.049). However, there was no statistical difference between sarcopenia and non-sarcopenia groups in thigh volume and surface. ROC curve analysis was conducted for four significant values (right and left calf volume, the mean calf volume, and the mean calf surface), and right calf volume showed the most valuable cut-off value. (Right calf volume 2.80m2, AUC 0.768; left calf volume 2.75m2, AUC 0.753; mean calf volume 3.06m2, AUC 0.774; mean calf surface 0.12m2, AUC 0.747)
Conclusion: It was confirmed that the four variables of calf volume and surface were variables that had a significant relationship with sarcopenia, and confirmed that right calf volume, which had the highest AUC value, could be used as the most significant variable. In addition, the cut-off of sarcopenia diagnosis could be set through ROC curve analysis for each variable.

Accuracy Comparison of 3D Face Scans Obtained by Portable Stereophotogrammetry and Smartphone Applications 70

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Michel BILA 1,2, Robin WILLAERT 1,2, Yi SUN 1,2, Jeroen VAN DESSEL 1,2

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Purpose: To compare the accuracy of three-dimensional (3D) facial scans captured by smartphone applications with a clinically approved portable stereophotogrammetry device.
Methods: Morphometric markers were placed on 8 points on the face of fifty participants. Facial 3D scans were captured with a Light Detection and Ranging (LiDAR) camera on an iPad Pro using 5

smartphone applications and a stereophotogrammetric 3D Vectra H1 camera. These 5 smartphone applications are Heges 3D Scanner (Marek Simonik, Ostrava, Czech Republic), Bellus FaceMaker (Bellus 3D Inc, Campbell, USA), ScandyPro (Scandy, New Orleans, USA), Scaniverse (Toolbox AI, San Diego, USA) and Trnio (Trnio, Los Angeles). The standard triangle language (stl.) format of the smartphone facial scans were automatically surface-based spatially aligned on the 3D Vectra H1 stl. of the corresponding participant. Linear and 3D measurements were performed in 3-Matic software (Materialise, Leuven, Belgium).
Results: The largest linear differences were found between the morphometric points of the Heges 3D scanner (3.4 +-1.5 mm) and ScanyPro (4.4 +-2.1 mm), and Vectra H1, while the smallest deviations were seen for the Bellus FaceMaker (2.2 +-1.2 mm) and Trnio (2.9 +-1.5 mm). Identical findings were obtained for the 3D comparison. Within the forehead region, which was the region with the smallest deviation, the Bellus FaceMaker (-0.16 +-0.47 mm3) and Trnio (-0.57 +-0.76 mm3) give the best similarity. Largest differences were again found for the Heges 3D scanner (0.86 +- 0.83) and ScanyPro (1.02 +-0.97).
Conclusion: From the five tested smartphone applications, three (Bellus FaceMaker, Trnio and ScandyPro) showed sufficient accuracy for facial scanning purposes.

TECHNICAL SESSION 12: 3D/4D Body Scanning Systems & Uses IV

Inclusive Data Collections - Approach and Challenges 05

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Abstract not available.

CHECKER: Real-time Scan Quality Checking and Associated User Experience 30

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In recent years there have been several substantial advances in mobile 3D body scanning technology and Size Stream has been, and will continue to be, engaged in this effort. In addition to improving measurement accuracy, Size Stream is improving the user experience of the scan process. We are providing accurate measurements and 3D body avatars that are suitable for fitness tracking, ready-to-wear/uniform sizing, and made-to-measure garment ordering with minimum friction. We will present our new machine-learning system designed to detect 'scan errors' in real time (CHECKER). We use the CHECKER results to guide the user in real time to take an error-free scan rather than alert the user after they have completed the scan process. The CHECKER system can detect obscured body parts and baggy clothing. Size Stream plans to extend the capabilities of CHECKER so that it can detect more 'scan errors' including, various pose errors, clutter, hair issues (down on the neck rather than tied up), and sub-optimal lighting.

Protocols for High-Quality Indoor and Outdoor Scanning of Clothed People 47

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With the advancements in high-quality scanning technology, which is becoming more accurate, convenient, and available to smaller labs, the recommendations and protocols should be discussed and established. The protocols are important to make sure that the required list of steps is carried out for the desired set of goals and to minimize the overall time required to carry out the preparation, scanning, and postprocessing steps. In this paper, we propose scanning protocols for clothed people in indoor and outdoor settings. The indoor settings should be more suitable for high-quality 3D scans, which should serve as a reference to the ground-truth human body. The outdoor setting should be more suitable for providing challenging scenarios, closer to the real world. We discuss the postprocessing steps required to align indoor and outdoor datasets for the best quality of ground-truth information. Finally, we overview existing use cases and applications using scanning datasets and recommend the corresponding protocols.

Automation of Photogrammetry Capture - Tools and Methods 68

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Abstract not available.

TECHNICAL SESSION 13: 3D/4D Technologies for Apparel

3D Scanning Technology for the Rapid Modelling of Fashion Clothing 46

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The present research study addresses the prevalent issues of inefficient and time consuming garment pattern design in the fashion industry despite the recent advances in 3D product design. Fashion designers often lack efficient tools and readily available templates, which hinders their productivity and limits creative exploration. In order to overcome these obstacles, a solution that aids in garment pattern design by providing a comprehensive resource for content-based retrieval of image and 3D point-cloud data is proposed. The introduced software tool leverages a curated database to offer pattern designers access to an extensive collection of diverse garment designs, encompassing various styles, cuts, and aesthetics. The developed 3D point cloud retrieval architecture was designed to learn a similarity metric tailored for garments represented as 3D point clouds allowing the efficient exploration as well as selection of design patterns based on structural and stylistic attributes. Via the exploitation of machine learning algorithms, the retrieval architecture significantly reduces the time and effort required for the design ideation phase. Additionally, a demonstration of the applied process concerning the digitizing physical garments using a 3D structural scanner was seamlessly integrated utilizing real-world garments into the presented system and storing them in a digital pattern database. This approach represents a pioneering solution for rapid garment prototyping from the designer's standpoint, providing a valuable aid that accelerates the design process and encourages creative exploration. In addition, this research contributes to the literature on retrieval and metric learning for 3D garment fashion retrieval, opening that way new avenues for research and development in garment design, prototyping, and digital fashion innovation. In conclusion, the introduced software serves as a comprehensive solution that addresses the productivity hindrance faced by fashion designers, offering a transformative approach to garment pattern design and contributing to advancements in the field of digital fashion.

A Comparative Study of 3D Simulation and Scanning Technologies for Virtual Fabric Testing Laboratory: Tensile Tester 17

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The textile and apparel industries are undergoing a digital transformation, leveraging three-dimensional (3D) apparel prototypes to increase efficiency and reduce costs. While 3D scanning and simulation technologies have advanced significantly, the development of virtual fabric testing equipment is still in its early stages. A virtual fabric test laboratory represents a promising solution to the challenges associated with traditional testing methods, such as high costs, extensive labor requirements, and material waste.

This study aims to bridge the gap between 3D simulation and real fabric appearance by comparing mesh-based models obtained through 3D scanning and simulation technologies. The goal is to evaluate if 3D simulation can accurately represent the real-world tensile behavior of fabrics. To achieve this, we created a virtual tensile tester in 3DS Max and used it to stretch virtual fabrics to obtain 3D models in CLO 3D software. We then contrasted the 3D simulated fabric - digitized from physical property tests using the CLO Fabric Kit - with results from 3D and 4D scanning. These comparative findings are anticipated to lay the groundwork for devising a virtual tensile test that accurately mirrors real-world fabric behavior, thereby bringing the virtual testing environment closer in visual resemblance to the physical one.

TECHNICAL SESSION 14: 3D Foot Scanning

Leveraging Key-Point Detection to Prevent Shoe Returns in Online Shopping 39

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More than half of all shoes ordered online are returned.1 Different shoe size systems, a lack of standards and deviating models lead to a high level of uncertainty on the part of consumers. As a

result, retailers lose up to 20% of their revenues and the environment is unnecessarily polluted by packaging and shipping. Furthermore, users spend an average of 32 minutes of their time returning a shoe. We have developed a solution that allows consumers to measure their feet at home with their smartphone by processing two images of their feet on a DIN-A4 sheet. To accurately recommend a size, two sets of data are required: the feet measurements and the shoe dimensions. This is why, on the one hand, a foot measuring algorithm was developed using two computer vision techniques: semantic segmentation and key point detection. This paper compares both methodologies and evaluates which one performs better on a distance similarity metric. On the other hand, a database was built up where the Last data, i.e., the inner shoe dimensions of the shoes per manufacturer, model and size, are stored. When measuring the foot in 2D, there are factors such as the point of view of the images or the image resolution that can influence the perfect foot measurement. Hence, a guided capturing system was developed to minimize them. Finally, to match them to the perfect fitting size, we performed in-person tests with the manufacturer's shoes over the last year to optimize the way of recommending them.

Practical Aspects of 3D Scanning Results Application in Shoe Last Design 28

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The need to improve the quality of manufactured footwear is especially acute today for special shoes. In order to analyze the conformity of the existing forms of lasts for military shoes with the shapes of the feet of consumers, a 3D study of the feet of representatives of the mobilization reserve has been carried out. Based on the results of anthropometric studies, taking into account the specified requirements, a new improved shape of a last with an increased width was developed, which allows placing an orthotic inside the finished shoe. The developed last was used for manufacturing the test footwear samples, which were tested by fighters in combat and during training. For four patients, individual insoles have been designed and manufactured based on the scanned footprints on polyfoam. A practical experiment has also been carried out on the development and manufacture of individual unloading insoles for a soldier who has recently been injured, had severe wounds on both legs and underwent a series of surgeries, as a result of which part of his lower leg muscles do not function, which leads to difficulty walking. The studies and practical experiments carried out in the work have shown that today, 3D scanning is an important and effective way to obtain initial data both for anthropometric studies as well as for the practical application of the results for designing the elements of the inner shape of footwear.

Methodological and Statistical Approaches for the Assessment of Foot Shape Using Three-Dimensional Foot Scanning: A Scoping Review 25

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Objective: The objectives of this study were to: (i) review and provide a narrative synthesis of three-dimensional (3D) foot surface scanning methodological and statistical analysis protocols, and (ii) develop a set of recommendations for standardising the reporting of 3D foot scanning approaches.
Methods: A systematic search of the SCOPUS, ProQuest, and Web of Science databases were conducted to identify papers reporting 3D foot scanning protocols and analysis techniques. To be included, studies were required to be published in English, have more than ten participants, and involve the use of static 3D surface scans of the foot.
Papers were excluded if they reported two-dimensional footprints only, 3D scans that did not include the medial arch, dynamic scans, or derived foot data from a full body scan.
Results: The search yielded 78 relevant studies from 17 different countries. The available evidence showed a large variation in scanning protocols. The subcategories displaying the most variation included scanner specifications (model, type, accuracy, resolution, capture duration), scanning conditions (markers, weightbearing, number of scans), foot measurements and definitions used, and statistical analysis approaches. A 16-item checklist was developed to improve the consistency of reporting of future 3D scanning studies.
Conclusion: 3D foot scanning methodological and statistical analysis protocol consistency and reporting has been lacking in the literature to date. Improved reporting of the included subcategories

could assist in data pooling and facilitate collaboration between researchers. As a result, larger sample sizes and diversification of population groups could be obtained to vastly improve the quantification of foot shape and inform the development of orthotic and footwear interventions and products.

Automated Shoe Metrology by X-Ray Computed Tomography 48

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Automation of shoe metrology is crucial to providing fit information for shoes on a large scale. Here, we examine a segmentation technique to extract the inner shoe volume (ISV) from Computed Tomography (CT) data - the proposed approach leverages artificial neural networks to extract shoe parts for automated metrology precisely. The neural network architecture is customized to facilitate the extraction of ISV by integrating spatial attention mechanisms. Furthermore, a neural network segmentation algorithm removes filler materials virtually. This process yields enhancements of 1.3% in F1-score through material removal and an additional 1.4% through the incorporation of spatial attention. Notably, spatial attention mechanisms yield improved outcomes at the aperture of the shoe. The elimination of filler materials reduces false positive segmentations. The segmentation outcomes are utilized to generate surface meshes. These are compared to surface meshes derived from annotated data. We measure an average Hausdorff distance between annotated and labelled data of 2.1 mm. The discrepancy is primarily attributed to deformations and artifacts. On both sets, we measure the effective shoe length. Precision and accuracy metrics for the extracted measurement from ANN-segmented data attain 0.8 mm and 1.8 mm, respectively. For meshes obtained from label data, the precision is 0.2 mm, and the accuracy is 2.5 mm. Our findings underscore the accuracy of the extracted shoe interior volumes, rendering them suitable for metrological applications. Limitations include unsolved issues with separation reliability and deformation.

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